# Geographic Information Systems in Water Resources
# Spatial Analysis Exercise

CUAHSI Virtual University, 2019
David Tarboton

**Goal**

The goal of this exercise is to serve as an introduction to Spatial Analysis with ArcGIS.

**Objectives**

- Use ArcGIS.com services to access and extract elevation data
- Interpolate data values at points to create a spatial field to use in hydrologic calculations. Use this to calculate watershed area average precipitation
- Use raster data and raster calculator functionality to calculate watershed attributes such as mean elevation, mean annual precipitation and runoff ratio.

**Computer and Data Requirements**

To carry out this exercise, you need to have a computer, which runs ArcGIS Pro. The necessary data are provided in the accompanying zip file, **SpatialAnalysisData.zip**.

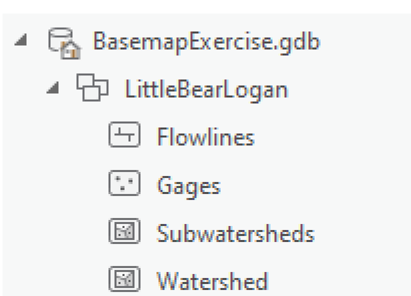
**Overview**

The purpose of this part of the exercise is to calculate average watershed elevation for subwatersheds of the Little Bear-Logan subbasin, and to calculate average precipitation over each of these subwatersheds using different interpolation methods. Average precipitation is then converted to a volume of precipitation and compared to runoff volumes using a runoff ratio. This provides an insight into the annual water balance of these watersheds, namely what fraction of precipitation is streamflow and what fraction is lost to evapotranspiration and other losses such as infiltration and groundwater recharge.

**Data**

The following data is provided in the **SpatialAnalysisData.zip** file:

BasemapExercise.gdb file Geodatabase from BasemapExercise.

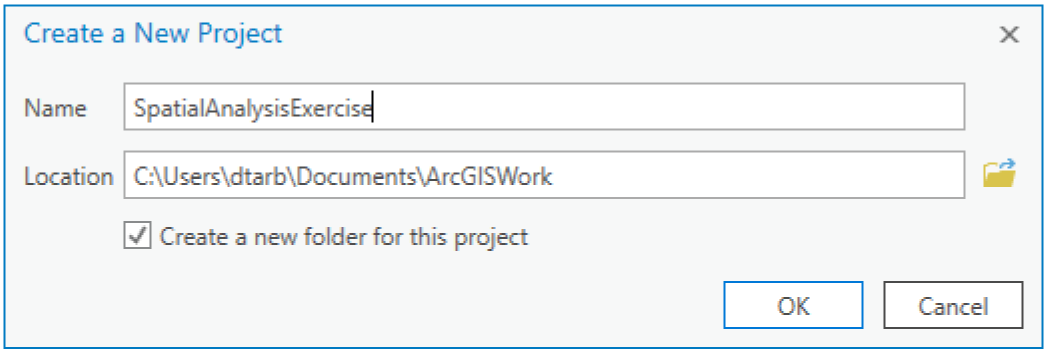


**LittleBearLoganAnnPrecip.csv**. Sites in and around Little Bear Logan Watershed where precipitation has been measured and data is available in the Global Historical Climatology Network (GHCN). T

**AssembleGHCNData.R, monthprecip.csv, monthdaycount.csv**. R script and intermediate files used in preparing the data as described in Appendix. You only need to use these if you want to apply or adapt this approach to another area or look into the data more deeply.

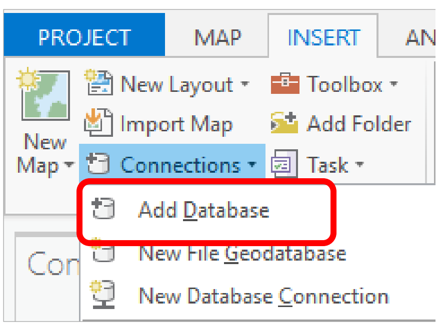
## 1. Loading the Data

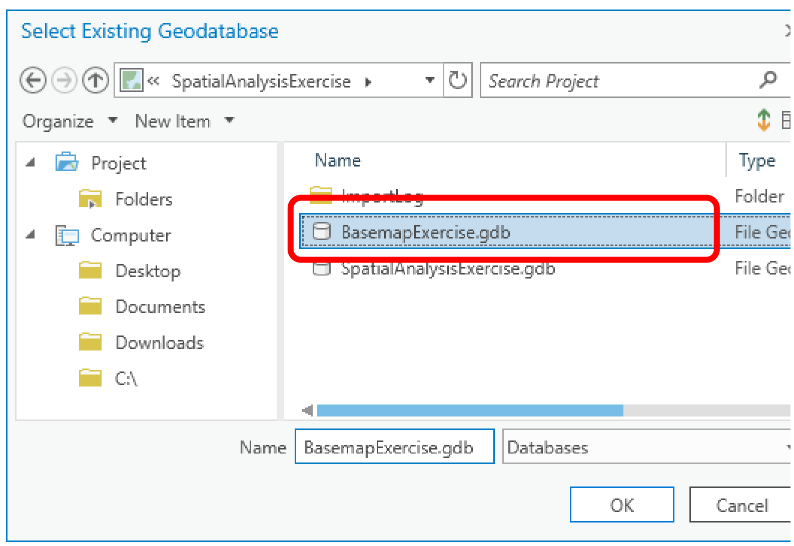
Open ArcGIS Pro and create a new Map project, **SpatialAnalysisExercise**



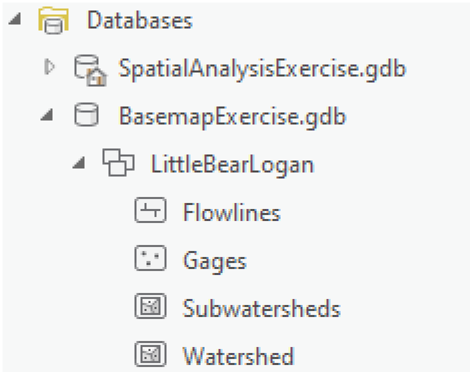

Copy the file **SpatialAnalysisData.zip** into the project folder created and unzip it.

Click **Connections** in the **Insert** tab and select **Add Database** to add the **BasemapExercise.gdb** to the project. This is another way to associate a Geodatabase with a project.

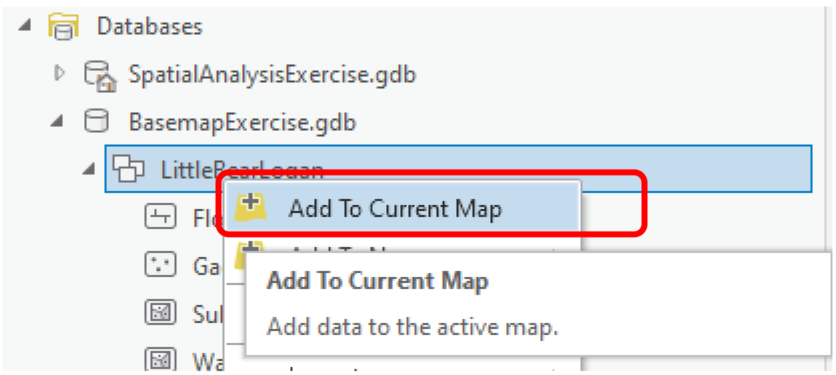


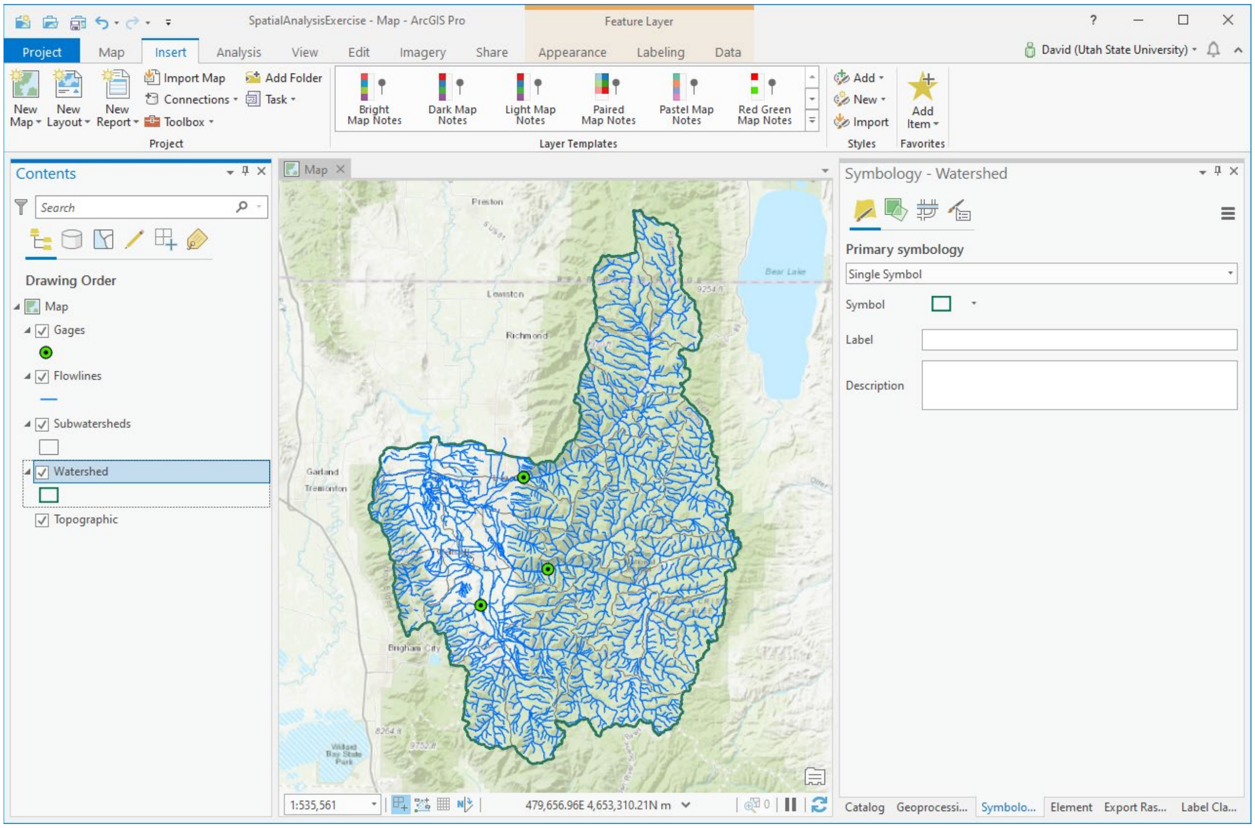
In the **Catalog** pane Expand BasemapExercise.gdb to see



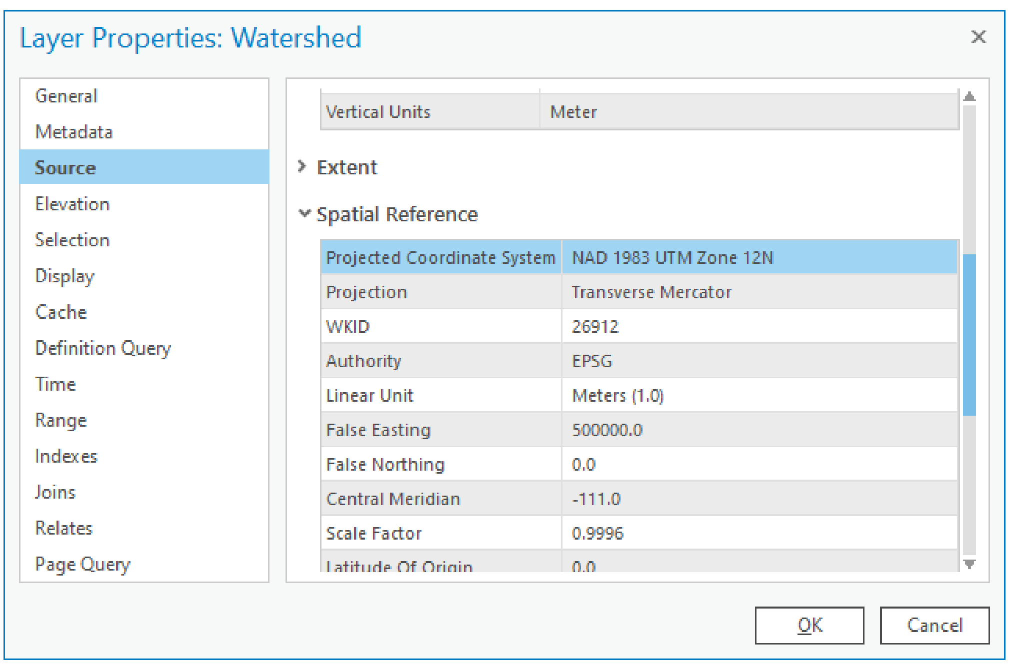

Right click on the **LittleBearLogan** feature dataset and "**Add To Current Map**".




You should obtain a map with all these features added.  Note I changed the symbology a bit.



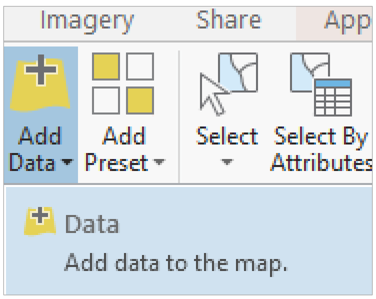

If you right-click on one these feature classes in the map legend, select **Properties** and **Source** and scroll down until you see **Spatial Reference** at the bottom of the layer properties, you'll see that they have the **NAD 1983 UTM Zone 12N** coordinate system. You should also see that the Linear Unit is meters.



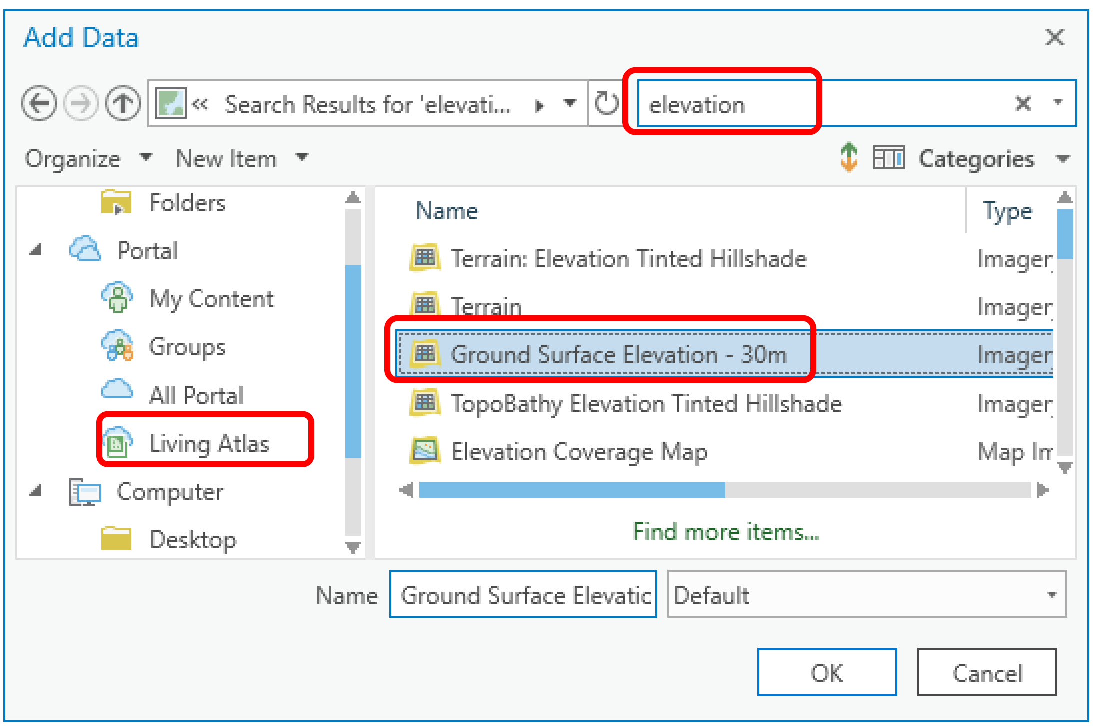
If you move the cursor around on the map, you may see that the coordinates at the bottom are in also in meters. When the data was added to the Map, its properties switched to that of the data being added.

Go to https://livingatlas.arcgis.com/ and search for 'elevation'. You should see that one of the first entries is 'Ground Surface Elevation 30 m' and if you read about this you see that this is 30m raster data extracted from the USGS's National Elevation Dataset. We will use this DEM in this exercise, but loading it directly from ArcPro.

Select **Add Data** to the Map



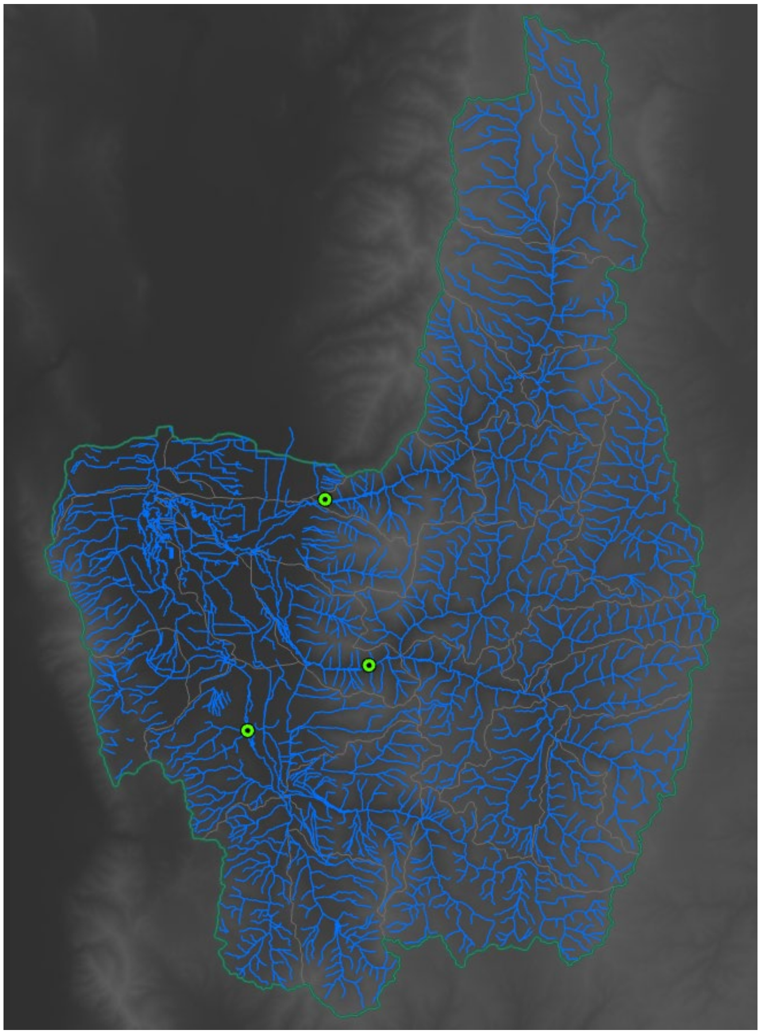

And among the options presented, select **Living Atlas.** In the **Search Portal: Living Atlas** type in **elevation** and among the options presented, select **Ground Surface Elevation 30 m**, the DEM identified in the web search.




Click OK. You should see a gray "Ground Surface Elevation – 30 m" layer appear on the map.

This data could also have been downloaded from the National Map viewer, [http://viewer.nationalmap.gov/viewer/](http://viewer.nationalmap.gov/viewer/), although the process is a bit more tedious. Here we are saving time taking advantage of the Living Atlas data services.

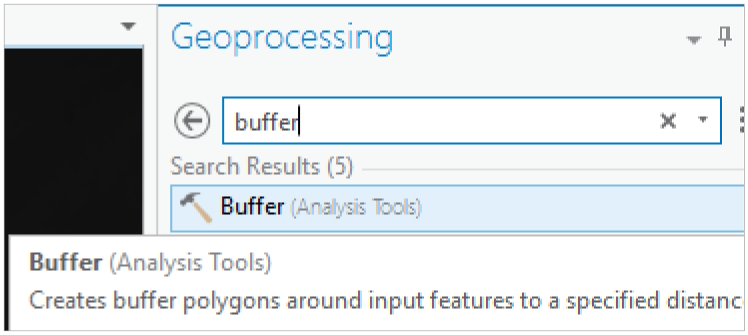
Your map should look similar to the following:



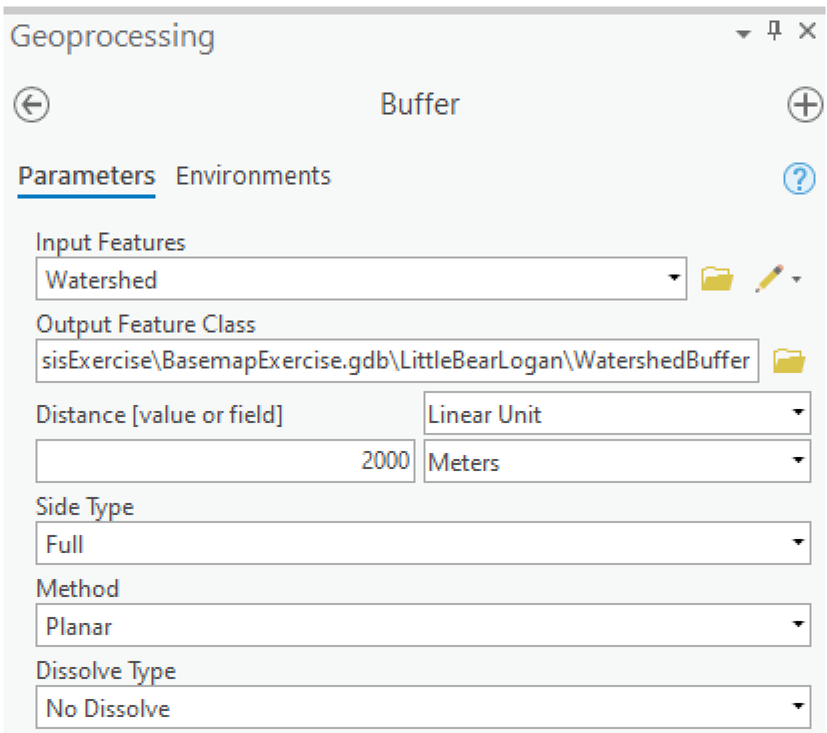
Save your **Project** document if you have not already.

Let's export data from this DEM to have a local copy to work with. First we need to define the area that we want to work with. Let's pick an area that has a 2000 m buffer around the basin.

In the Geoprocessing Panel, use the search box to search on "buffer" and select the **Buffer (Analysis)** tool.

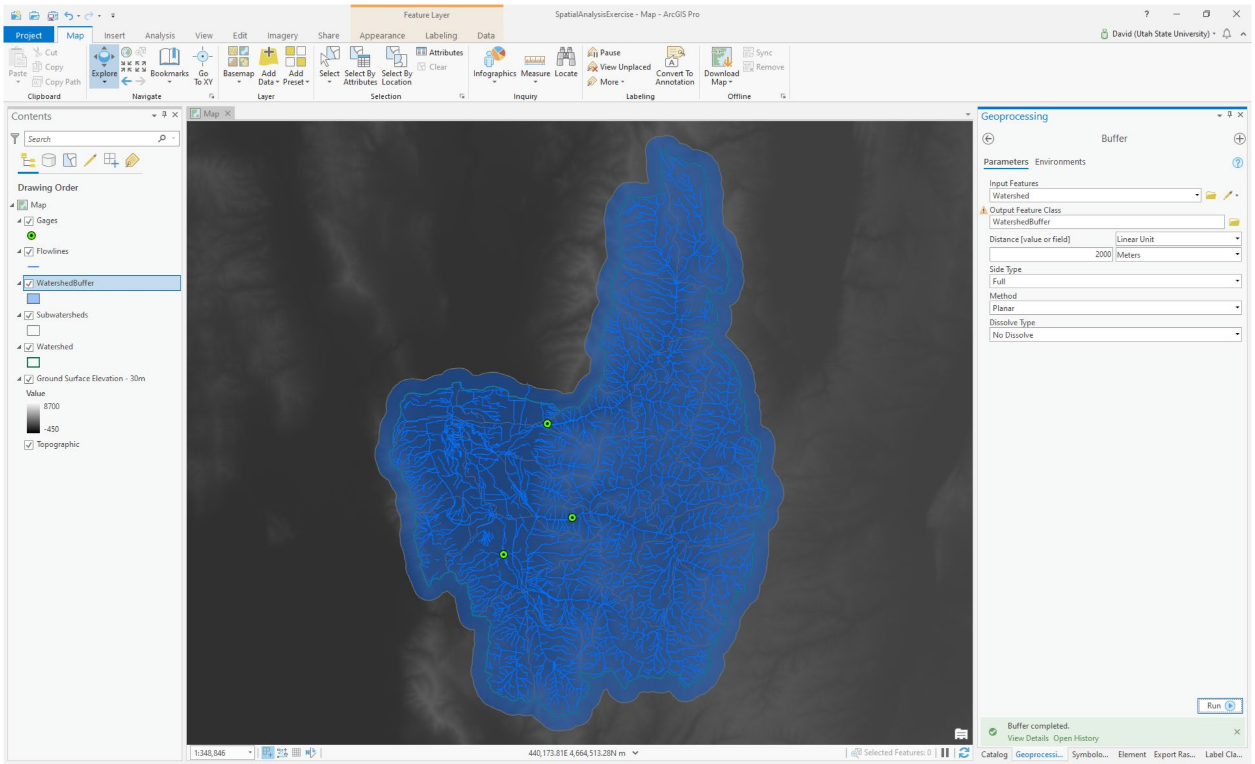



Set the inputs as follows and **Run** the tool.

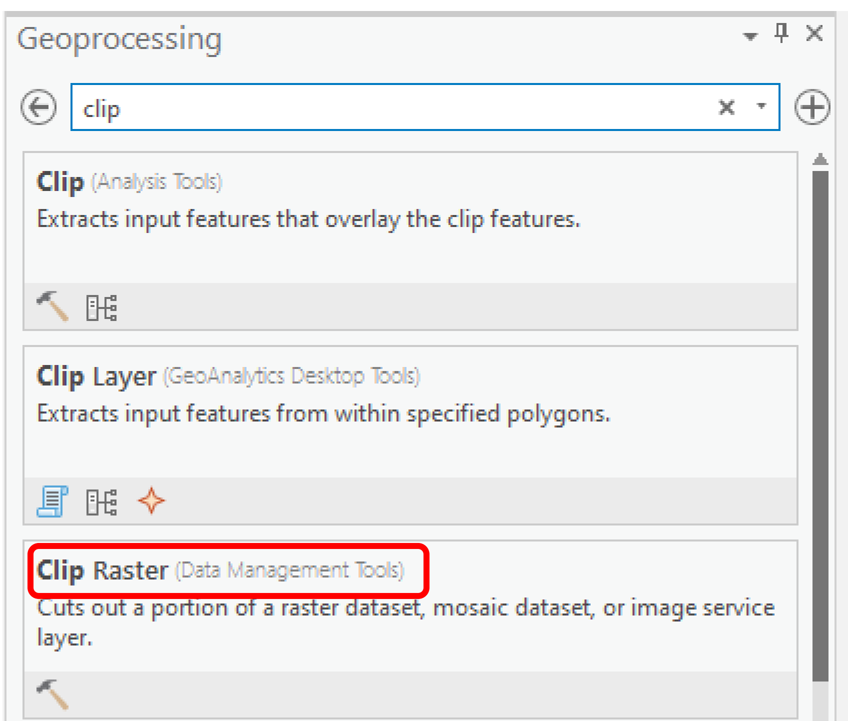


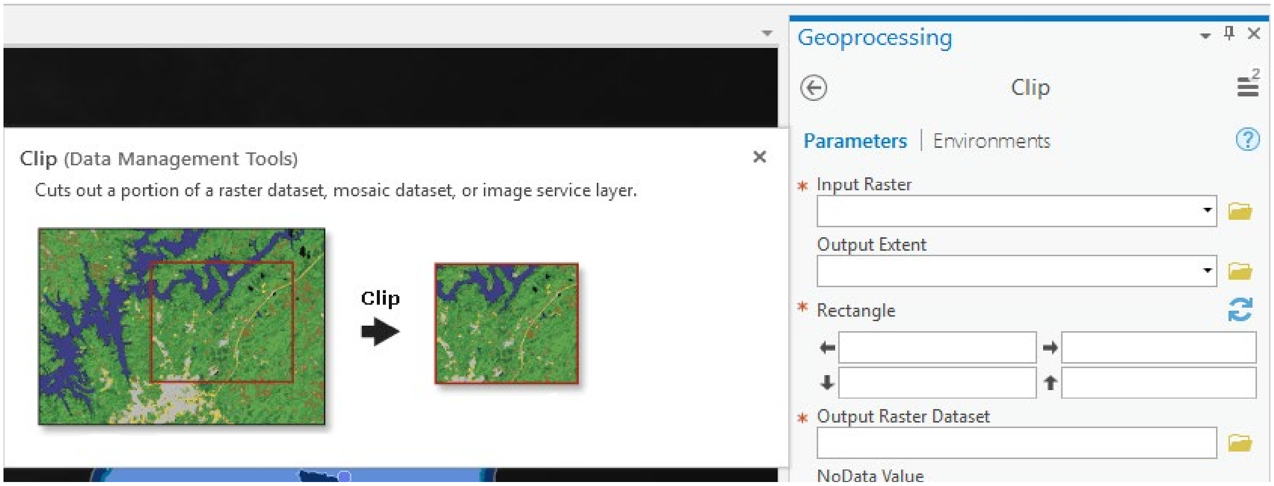

Note that I saved the result in the BasemapExercise.gdb LittleBearLogan feature dataset.

The result should be a polygon that is 2000 m larger around the edge of the basin. If necessary, use the Symbology tool to change the Buffer symbology to an **Outline** and then you can see the other feature classes underneath it.

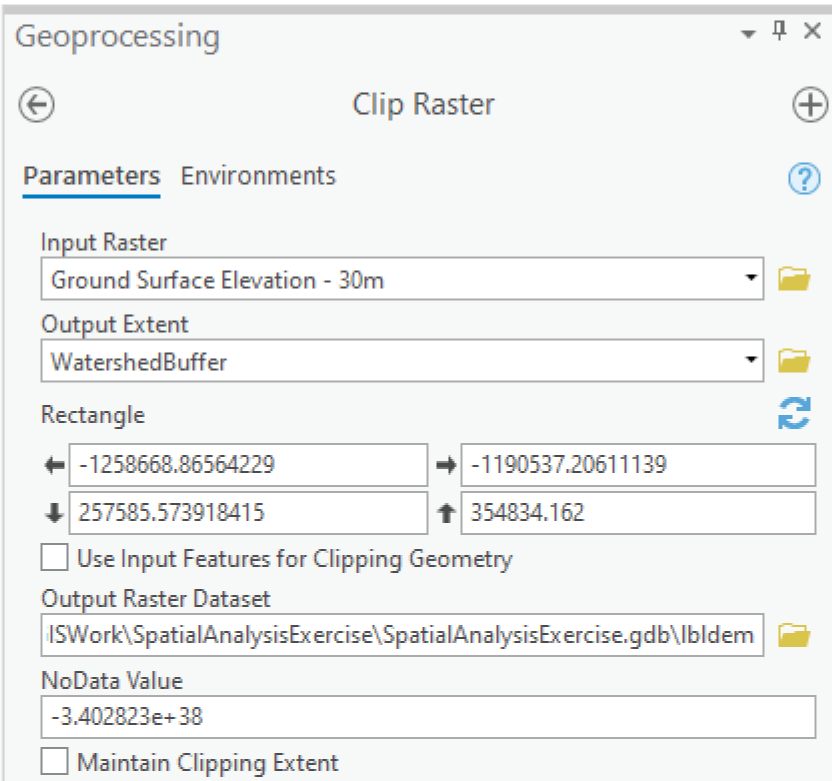



Use the search box to search on "clip" and select the **Clip Raster (Data Management)** tool. This tool was chosen because one of its allowable inputs is an image service.

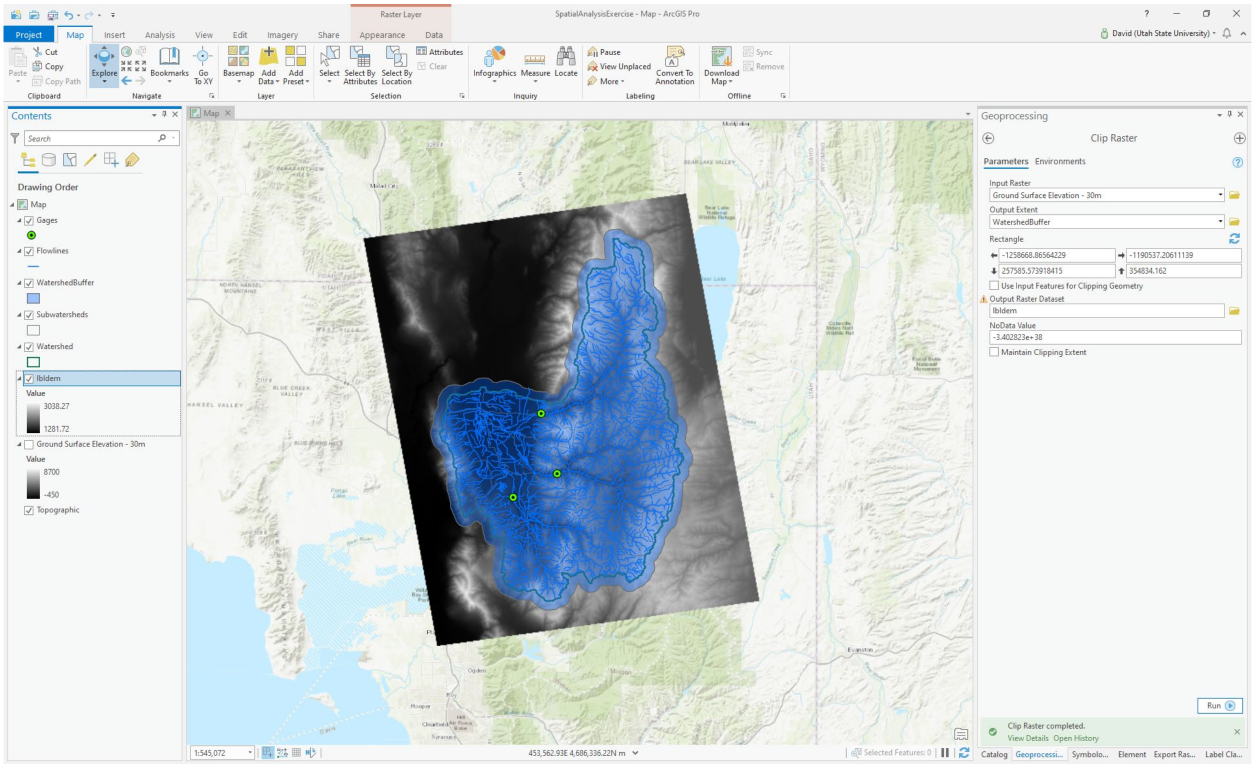





Set the inputs as follows (setting the output to go into SpatialAnalysisExercise.gdb) and **Run** the tool.




You should have a raster layer added to your ArcMap with a local subset from the DEM, that has the extent of WatershedBuffer and is easier to symbolize. Turn off the Ground Surface Elevation layers to see this display.

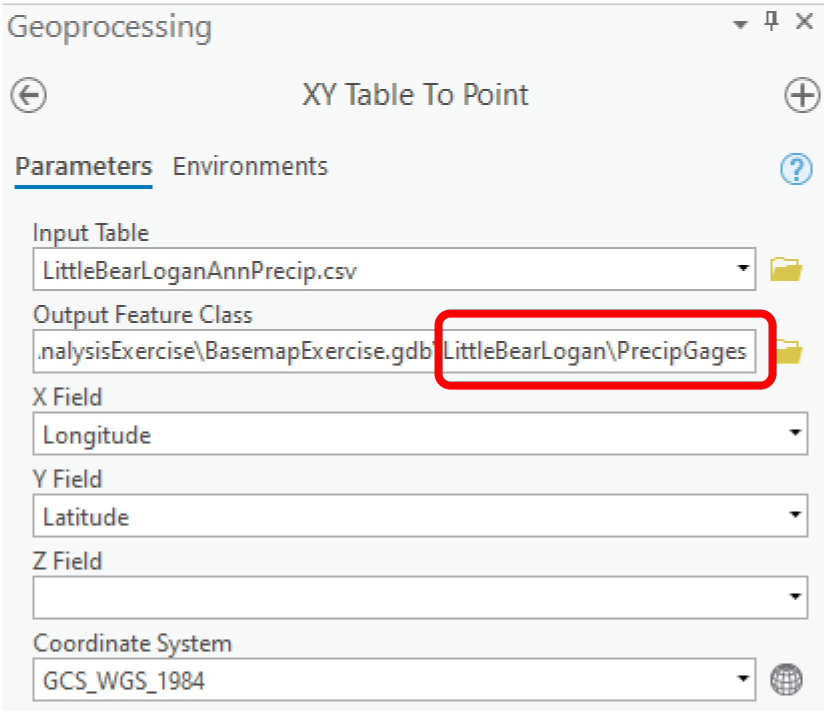


Note the skew appearance of the DEM lbldem just extracted. If you examine the **Layer Properties** for **Source ->Raster Information** for this you will see that it has a cell size of 30.92 m and in Spatial Reference **North America Albers Equal Area Conic** coordinate system. This is the resolution and coordinate system of the data as obtained from the ArcGIS elevation image service. This coordinate system is appropriate for display for all of North America and is skewed at the longitude of our area.

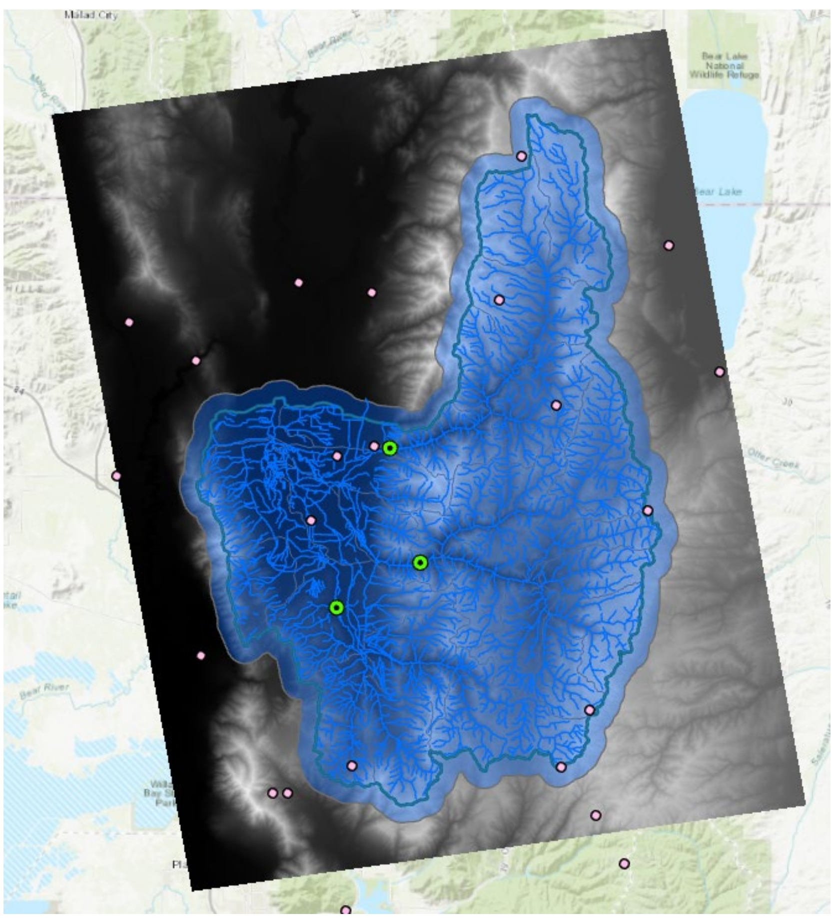
Let's add precipitation gages.

Select Add data and add LittleBearLoganAnnPrecip.csv.

Use Display XY Data on the table added to open the XY Table to Point tool and save the output feature class as PrecipGages in the LittleBearLogan feature dataset.

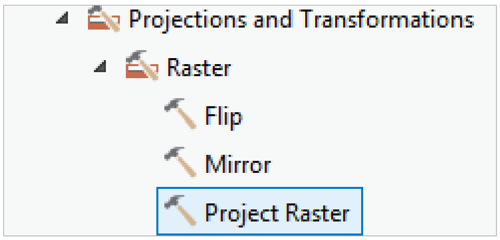



This should add precipitation gages to the map.  Symbolize them as you like.

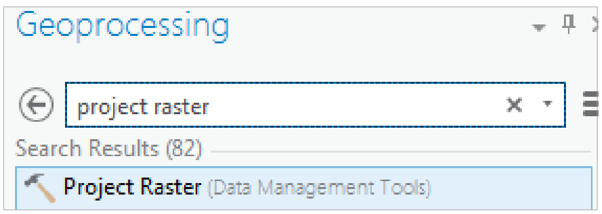


## 2. Projecting the DEM

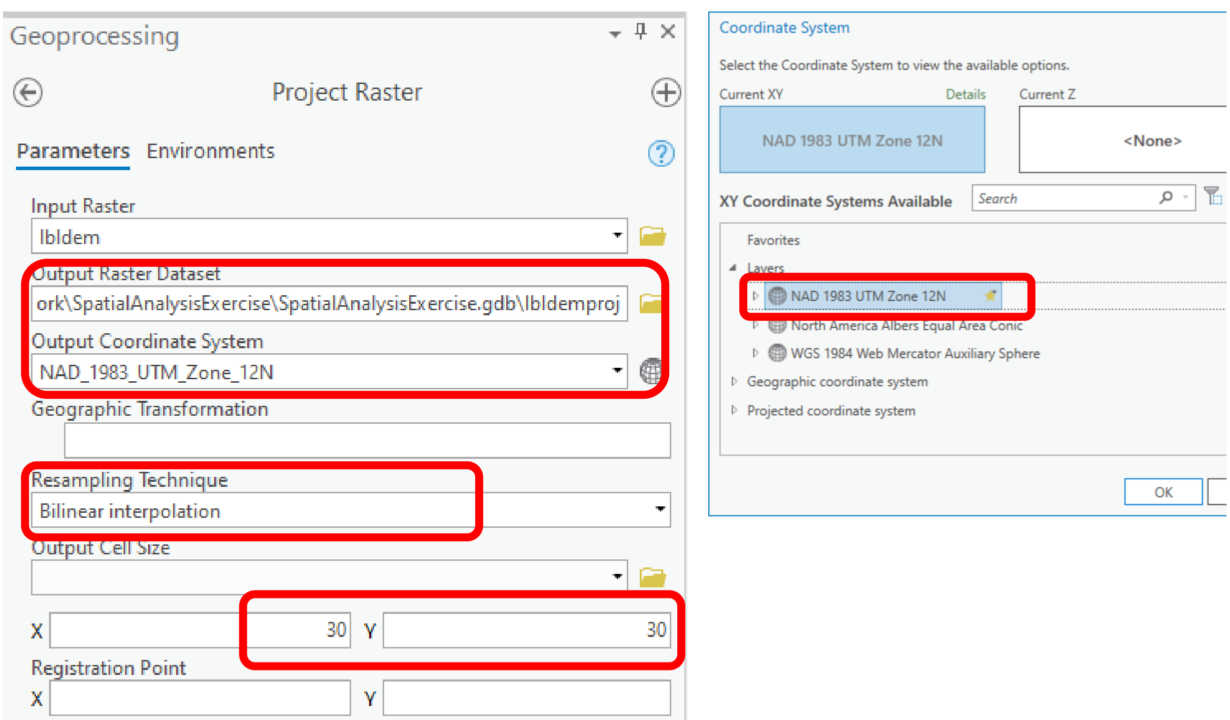
It is desirable to work with data in consistent coordinate systems. Let's project this DEM into the same projection as the LittleBearLogan Feature dataset (as we noted above the DEM from the web service was in a different coordinate system). Open the Toolboxes and open the tool **Data Management Tools → Projections and Transformations → Raster → Project Raster**. If you find this tool hard to locate,



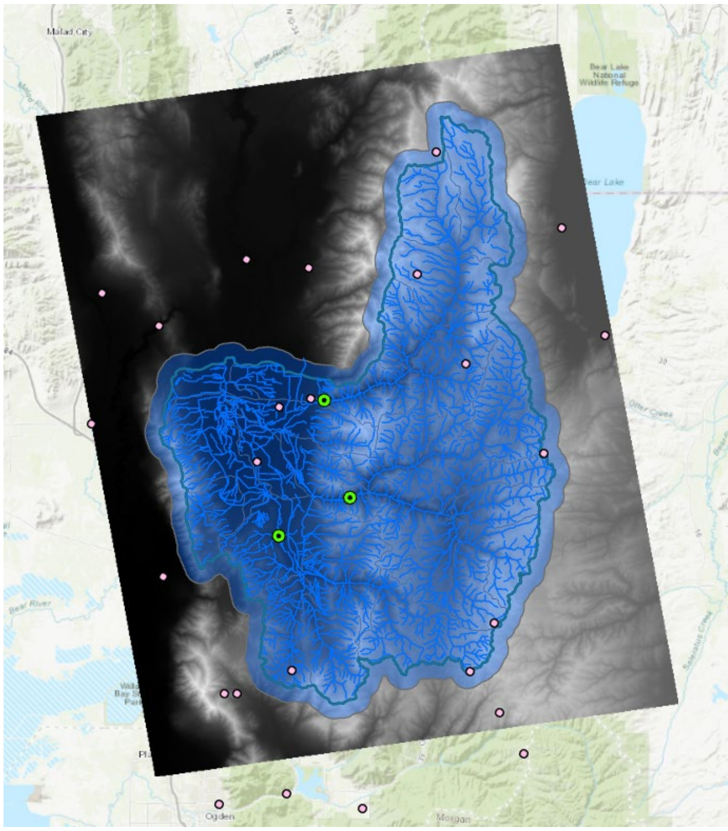

you can also search for it:



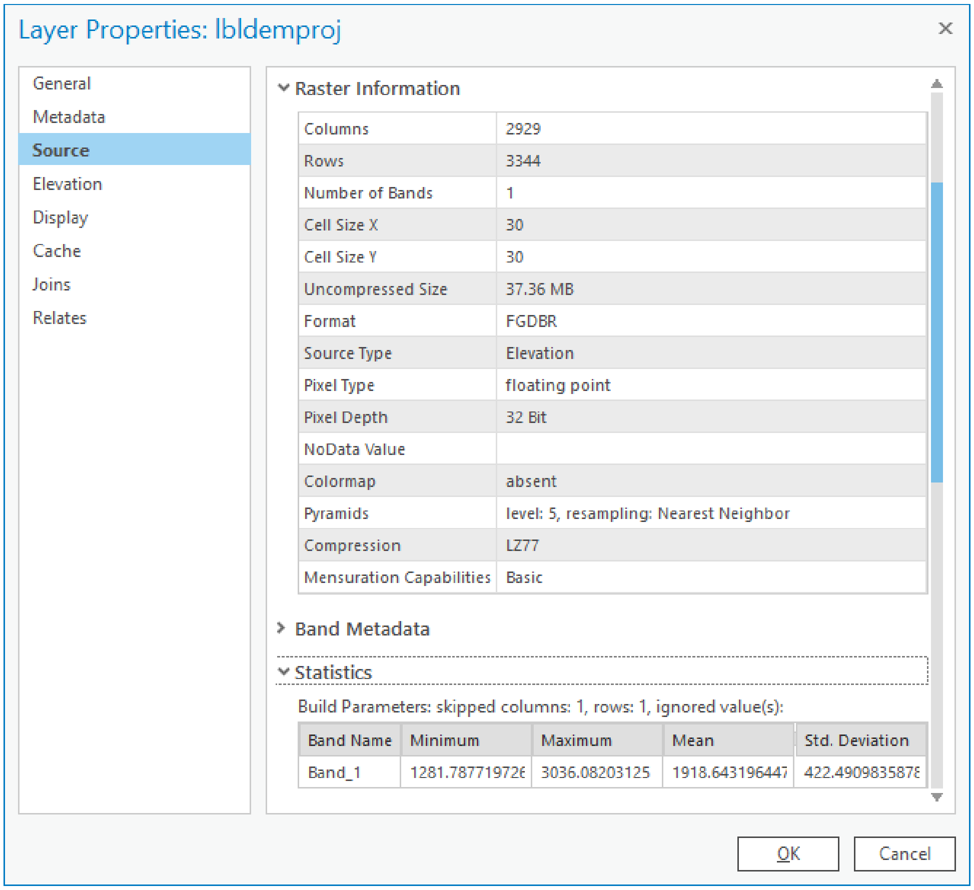

Set the inputs as follows to produce a projected raster **lbldemproj** in SpatialAnalysisExercise.gdb geodatabase with **30m** cells and the **NAD 1983 UTM Zone 12** coordinate system used for the basemap. Note that the **NAD 1983 UTM Zone 12** coordinate system is most easily set by clicking next to Output Coordinate System and selecting from existing Layers on the map.



The result should appear similar to:



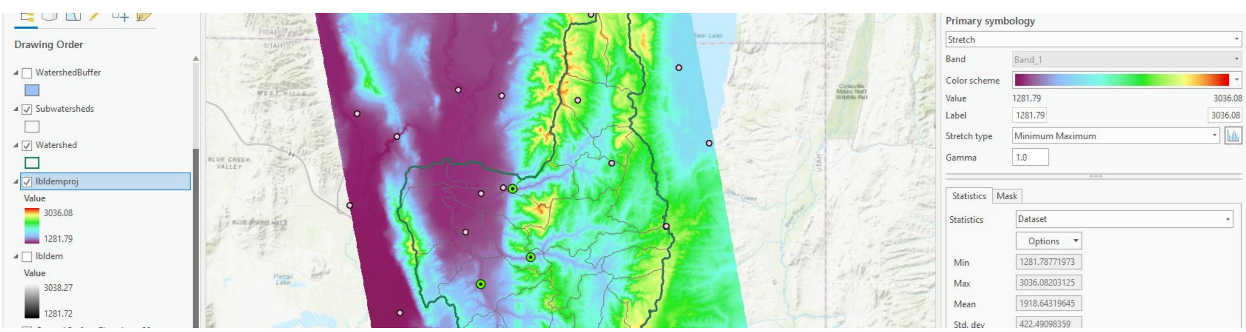

The spatial information about **lbldemproj** can be found by right clicking on the ProjDEM layer, then clicking on **Properties → Source → Raster Information**, and **Statistics**



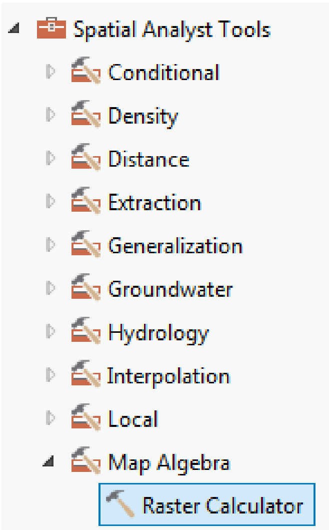

*To turn in: The number of columns and rows in the projected DEM. The cell size of the projected DEM. The minimum and maximum elevations in the projected DEM.*

## 3. Exploring the DEM

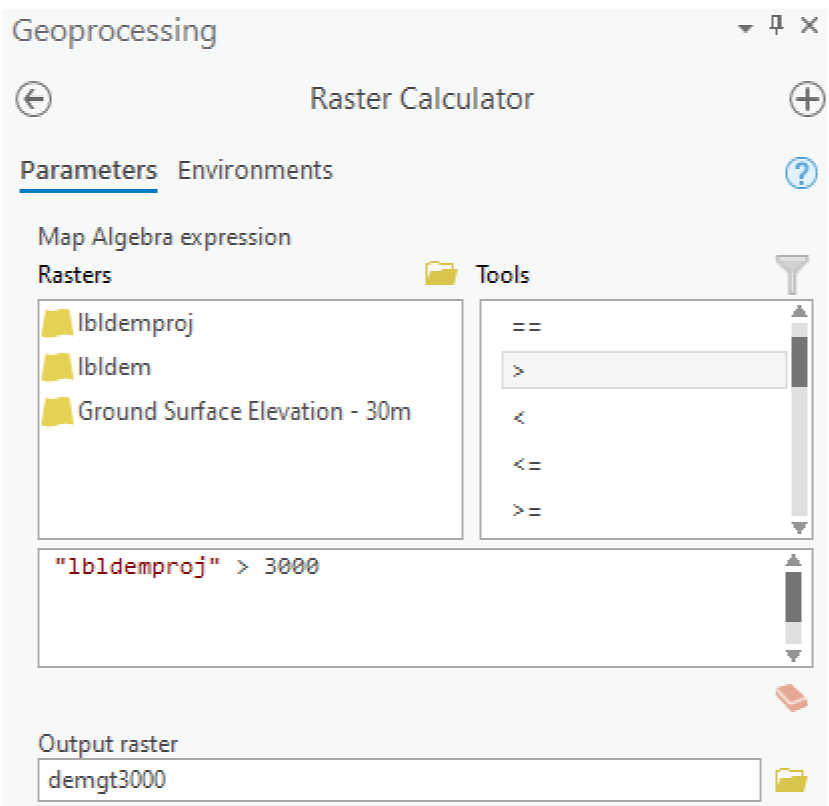
Change the symbology of the lbldemproj layer.




To explore the highest elevation areas in your DEM select **Spatial Analyst Tools → Map Algebra → Raster Calculator**.

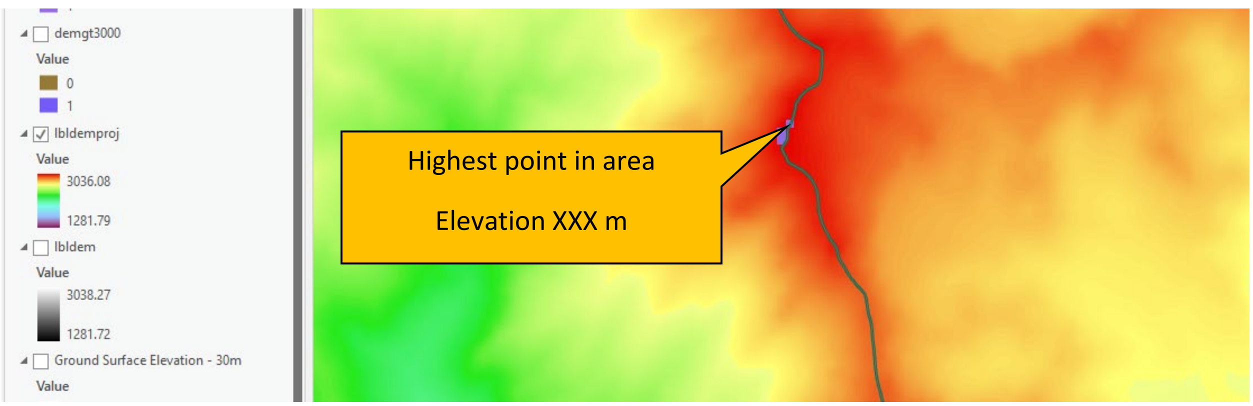



Double click on the **lbldemproj** layer with the DEM for this area. Click on the greater than “>” symbol and select a number less than the maximum elevation. This arithmetic raster operation will select all cells with values above the defined threshold. In the example below a threshold of 3000 m was used.




A new layer appears on your map. The majority of the map (brown color in the figure below) has a 0 value representing false (values below the threshold), and the purple region has a value of 1 representing true (elevations higher than 3000 meters). If necessary, change the symbology of the resulting map display so that you can see high elevation areas more clearly and zoom in on them.


Use the raster calculator again (with elevation 3030 meter threshold) and the explore tool to identify the grid cell of maximum elevation in **lbldemproj**.  Take a screen shot similar to the below and indicate the grid cell with the highest elevation

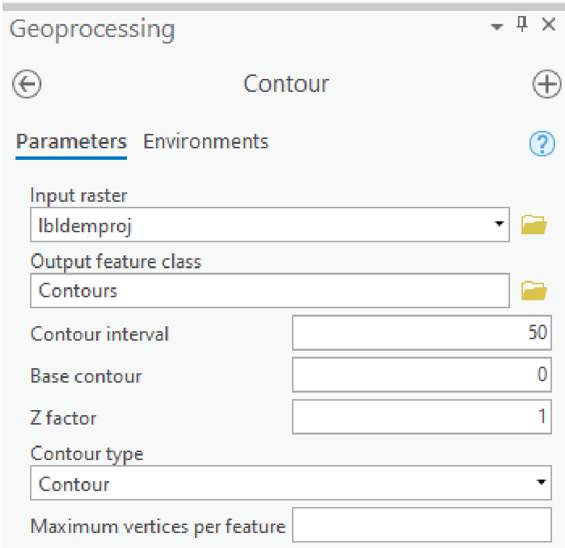



Note that the above label was placed on the screen shot using a word processor.  This is a bit easier than fiddling with labels in ArcGIS.

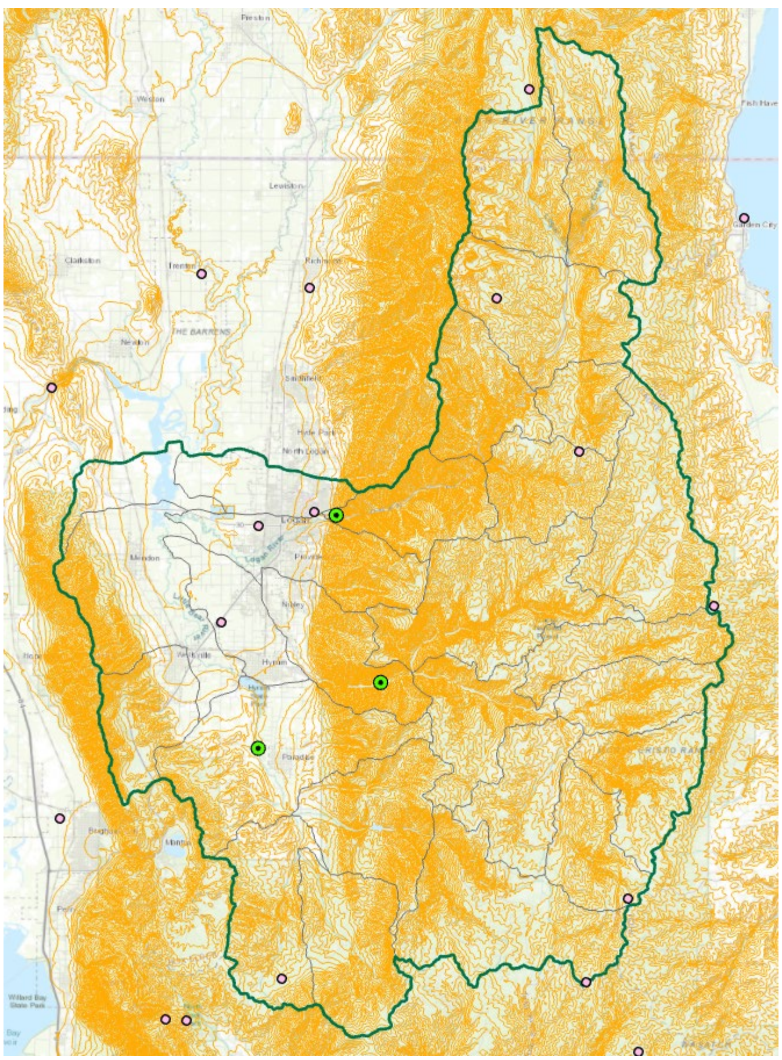
*To turn in:  A screen shot showing the location of the highest elevation value in the Little Bear Logan DEM.*

## 4. Contours and Hillshade

Contours are a useful way to visualize topography.  Select **Spatial Analyst Tools → Surface → Contour**. Select the inputs as follows, with a 10m contour interval:

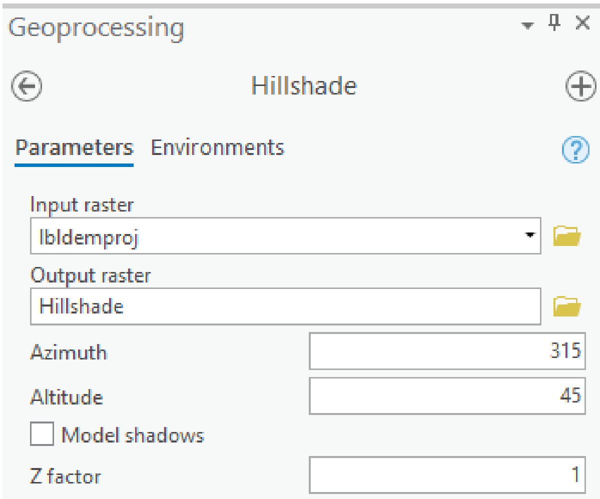


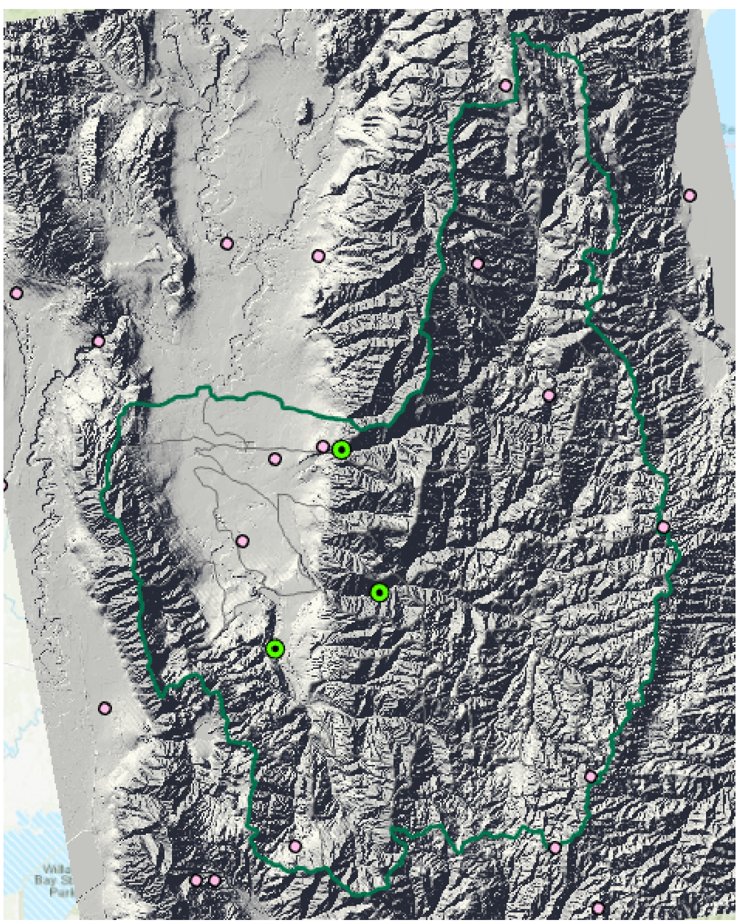

A layer is generated with the topographic contours for Little Bear Logan area. Notice the big difference in Terrain Relief in Cache valley to the west and Bear River Range to the east.



Another option to provide a nice visualization of topography is Hillshading.

Select **Spatial Analyst Tools → Surface → Hillshade** and set the factor Z to a higher value to get a dramatic effect and leave the other parameters at their defaults (the following hillshade is produced with a Z factor of 10). Click OK. You should see an illuminated hillshaded view of the topography.



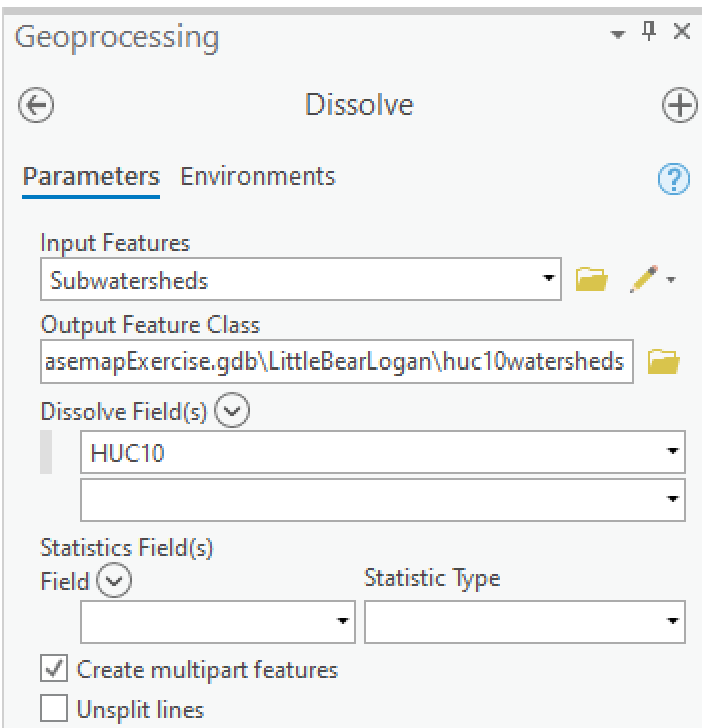



*To turn in: A layout with a depiction of topography either with elevation, contour* ***or*** *hillshade in nice colors. Include the streams from NHDPlus and watershed and sub-watersheds from the BasemapExercise.gdb LittleBearLogan feature dataset.*

## 5. Zonal Average Calculations

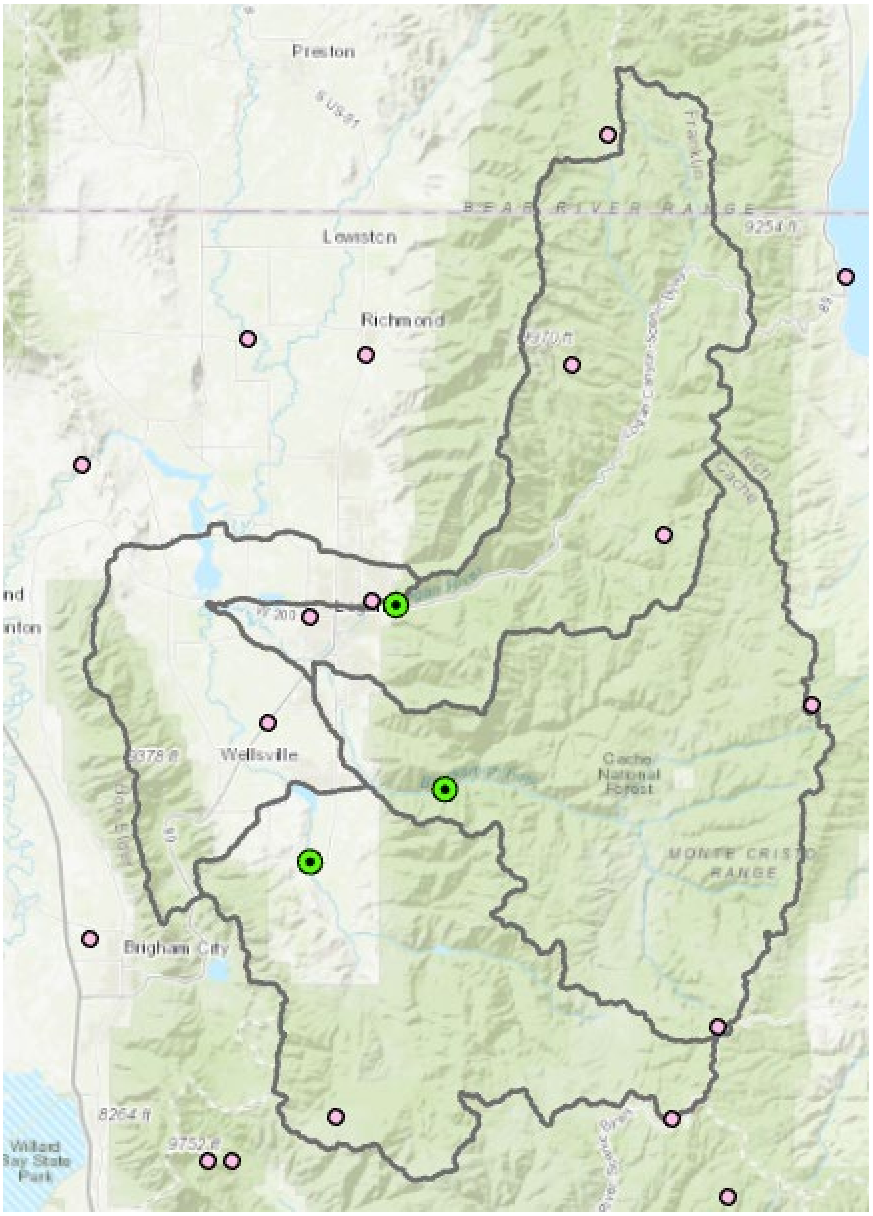
In hydrology it is often necessary to obtain average properties over watersheds or subwatersheds. The Zonal functions in Spatial Analyst are useful for this purpose. Let's do this at the HUC10 watershed scale.

Locate the Dissolve Geoprocessing tool and set the inputs as follows

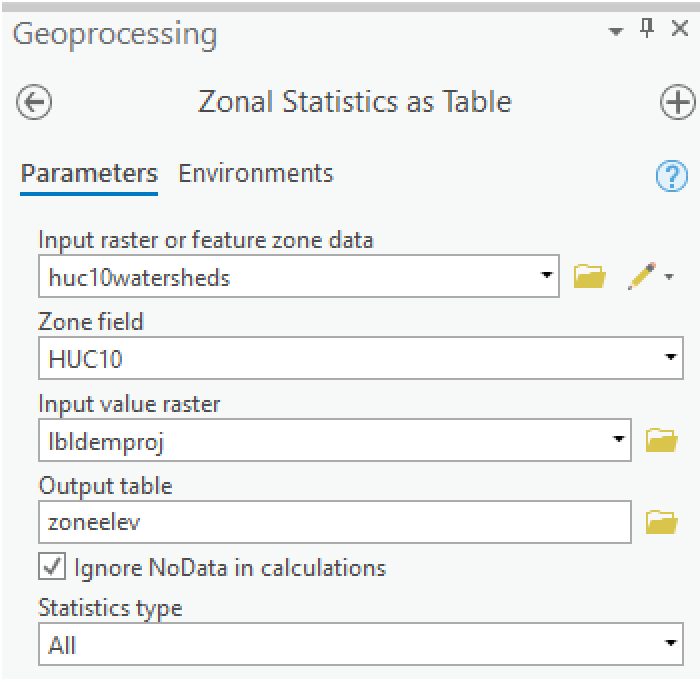



The resulting feature class has 4 features

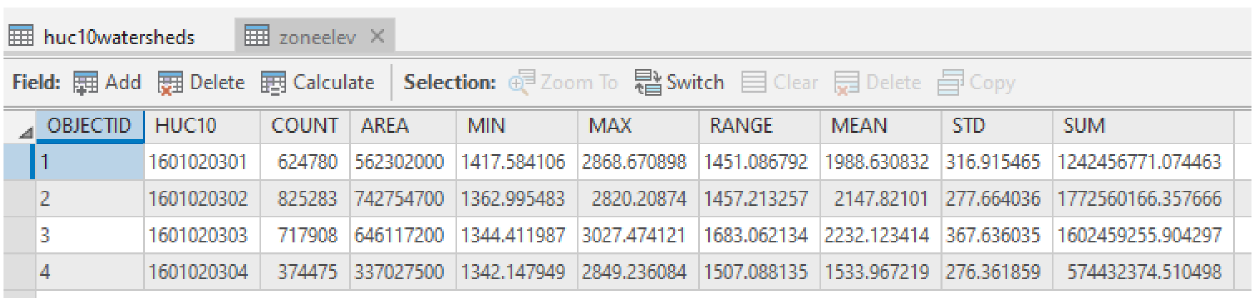
| OBJECTID | Shape | HUC10 | Shape_Length | Shape_Area |
|---|---|---|---|---|
| 1 | Polygon | 1601020301 | 143516.329307 | 562295332.404097 |
| 2 | Polygon | 1601020302 | 167937.734998 | 742766372.217383 |
| 3 | Polygon | 1601020303 | 172341.610482 | 646088951.880712 |
| 4 | Polygon | 1601020304 | 115612.695643 | 337013525.957088 |




Select **Spatial Analyst Tools → Zonal → Zonal Statistics as Table**. Set the inputs as follows:



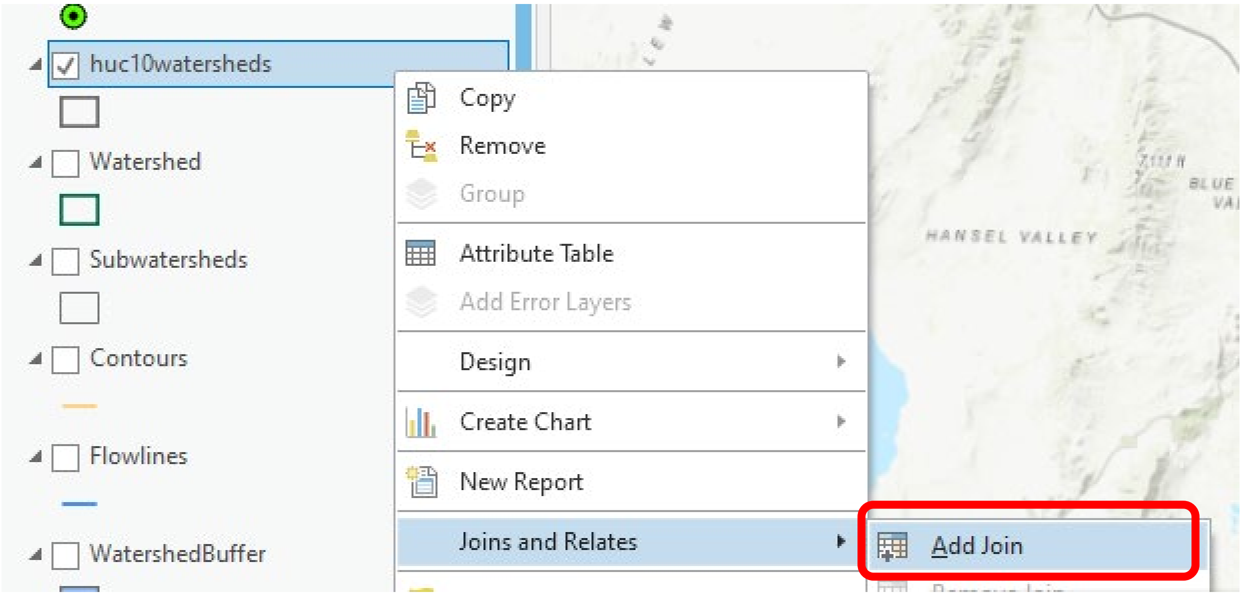

Click OK.  A table with zonal statistics is evaluated and added to the map (at the bottom of the map display). Right-click to **open** the table.



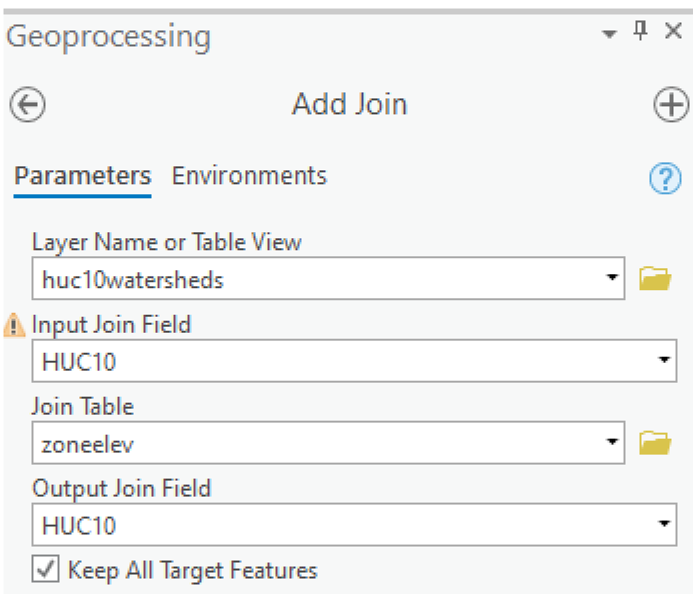

| OBJECTID | HUC10 | COUNT | AREA | MIN | MAX | RANGE | MEAN | STD | SUM |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1601020301 | 624780 | 562302000 | 1417.584106 | 2868.670898 | 1451.086792 | 1988.630832 | 316.915465 | 1242456771.074463 |
| 2 | 1601020302 | 825283 | 742754700 | 1362.995483 | 2820.20874 | 1457.213257 | 2147.82101 | 277.664036 | 1772560166.357666 |
| 3 | 1601020303 | 717908 | 646117200 | 1344.411987 | 3027.474121 | 1683.062134 | 2232.123414 | 367.636035 | 1602459255.904297 |
| 4 | 1601020304 | 374475 | 337027500 | 1342.147949 | 2849.236084 | 1507.088135 | 1533.967219 | 276.361859 | 574432374.510498 |

This contains statistics of the value raster, in this case elevation from **lbldemproj** over the zones defined by the polygon feature class **huc10watersheds**.  The HUC10 field in this zone table may be used to join these values with attributes of the huc10watersheds feature class.

Right click on huc10watersheds and select **Joins and Relates → Add Join**.



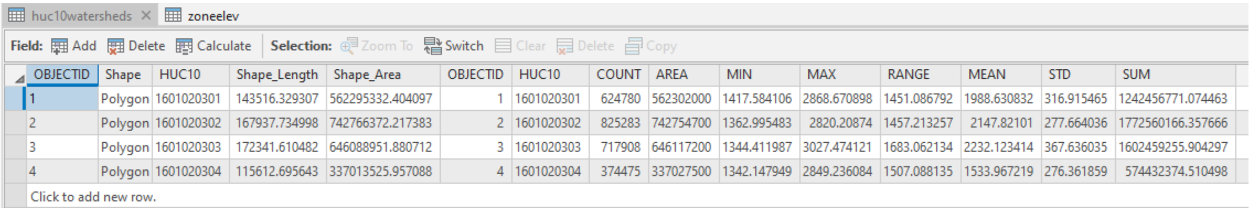

Select HUC10 as the field in this layer (huc10watersheds) that the join will be based on, zoneelev as the table to join to this layer, and HUC10 again as the field in the table to base the join on.




Note the warning, which states: "The join field HUC10 in the join table huc10watersheds is not indexed. To improve performance, we recommend that an index be created for the join field in the join table."

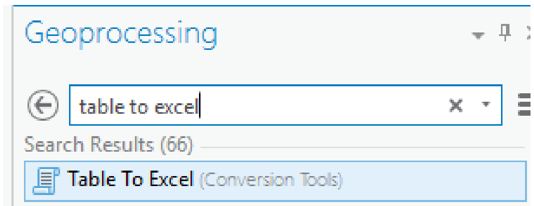
This warning can be ignored for this particular dataset because this table is sufficiently small, so the presence of indices to speed up the data queries does not make any noticeable difference.

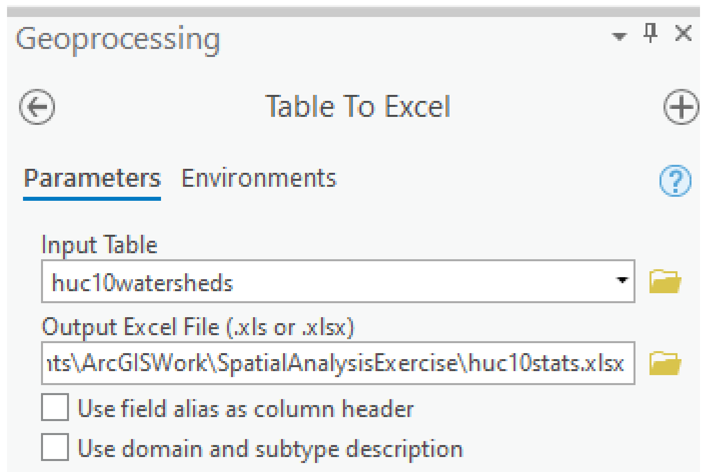
Open the huc10watersheds attribute table and scroll across. You'll see the statistics have been added to the attributes that this feature class already held.




| OBJECTID | Shape | HUC10 | Shape_Length | Shape_Area | OBJECTID | HUC10 | COUNT | AREA | MIN | MAX | RANGE | MEAN | STD | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Polygon | 1601020301 | 143516.329307 | 562295332.404097 | 1 | 1601020301 | 624780 | 562302000 | 1417.584106 | 2868.670898 | 1451.086792 | 1988.630832 | 316.915465 | 1242456771.074463 |
| 2 | Polygon | 1601020302 | 167937.734998 | 742766372.217383 | 2 | 1601020302 | 825283 | 742754700 | 1362.995483 | 2820.20874 | 1457.213257 | 2147.82101 | 277.664036 | 1772560166.357666 |
| 3 | Polygon | 1601020303 | 172341.610482 | 646088951.880712 | 3 | 1601020303 | 717908 | 646117200 | 1344.411987 | 3027.474121 | 1683.062134 | 2232.123414 | 367.636035 | 1602459255.904297 |
| 4 | Polygon | 1601020304 | 115612.695643 | 337013525.957088 | 4 | 1601020304 | 374475 | 337027500 | 1342.147949 | 2849.236084 | 1507.088135 | 1533.967219 | 276.361859 | 574432374.510498 |

In the Geoprocessing panel, select Table to Excel and specify Subwatershed as the input Table, and SubwatershedStats as output Excel file.




If you open up the resulting huc10stats Excel file you'll see the descriptive statistics there for these huc10 watersheds.

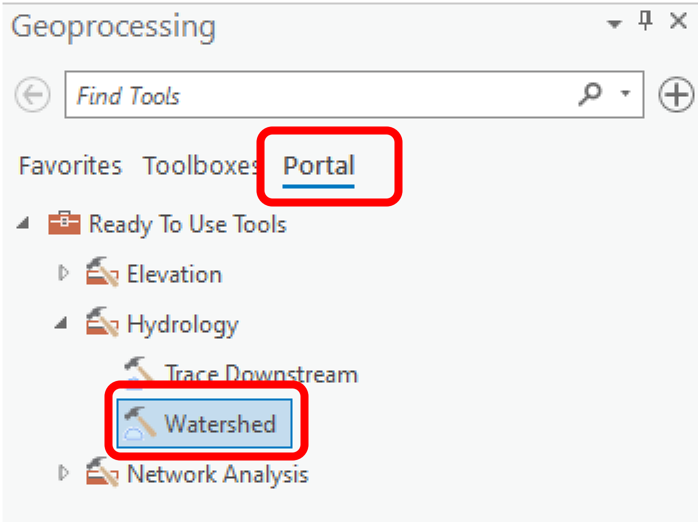
Determine the mean elevation and elevation range of each huc10 watersheds in the Little Bear Logan subbasin.

*To turn in: A table giving the HUC10, mean elevation, and elevation range for each watershed in the huc10 watersheds feature class. Which watershed has the highest mean elevation? Which watershed has the largest elevation range?*

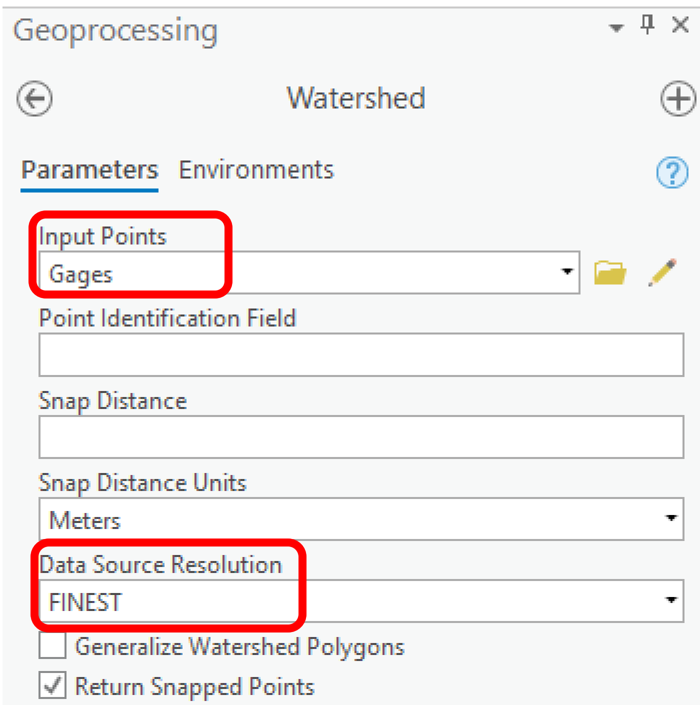
## 6. Calculation of Area Average Precipitation using Thiessen Polygons

Now to do something really useful. We will calculate the area average mean annual precipitation over the watershed using Thiessen polygons. Thiessen polygons associate each point in a watershed with the nearest raingage. Let's do this for watersheds draining to each stream gage.

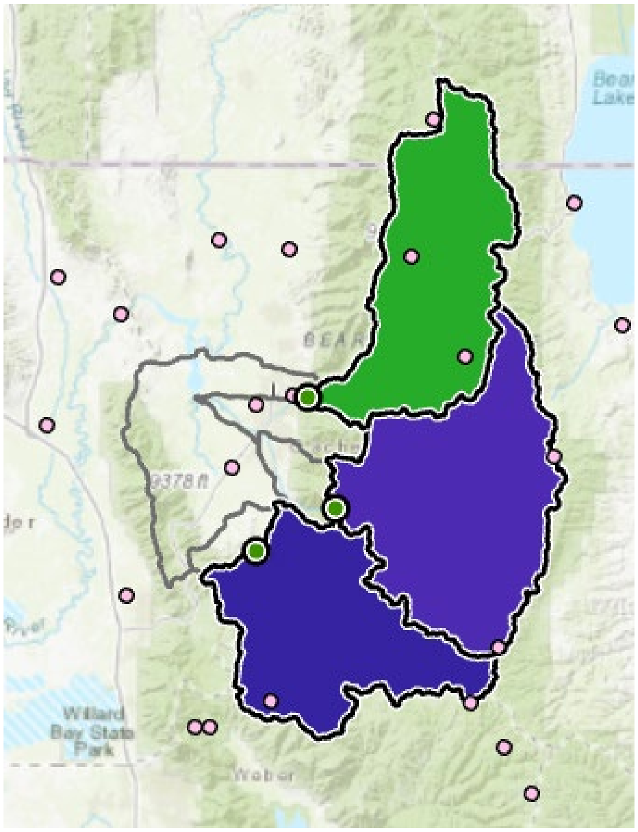
In the geoprocessing panel locate the Watershed tool in Ready to Use Tools under Portal




Set input points as Gages and Data Source Resolution FINEST.



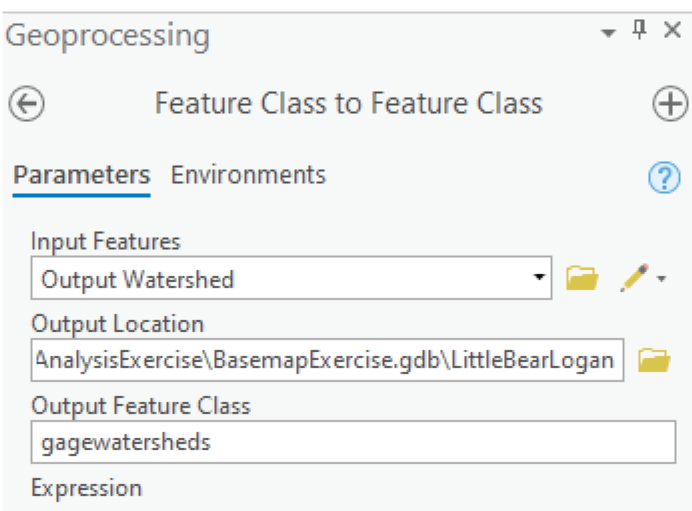

Click Run.  Three watersheds should be delineated.



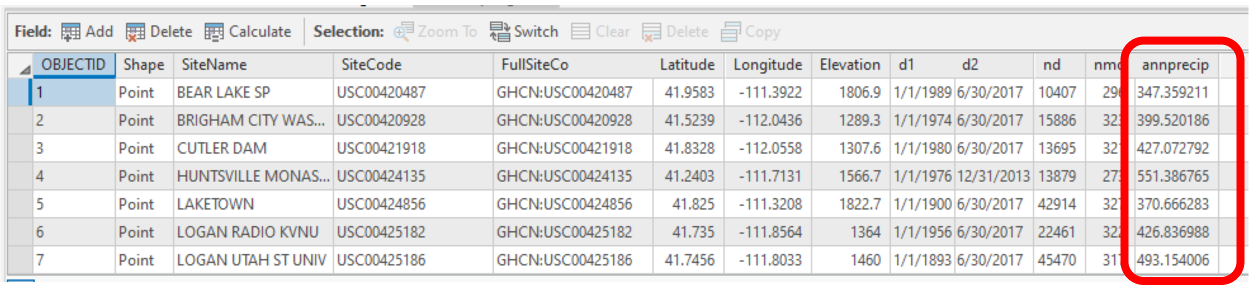

It may be that you are not able to do this due to this function using ESRI cloud credits that may not have been assigned to your account. You may need to work with your university instructor and ESRI site license manager to get this capability for your ESRI account.

Alternatively, you may do this for the HUC10 watersheds, instead of delineated watersheds.

Right Click on OutputWatershed from the Watershed delineation and select Data -> Export Features to open the Feature Class to Feature Class tool. Name the result gagewatersheds and put it in the LittleBearLogan feature dataset.

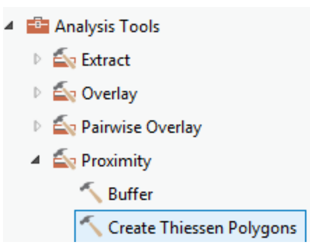


Turn on the **PrecipGages** layer in the map display and open their attribute table. You'll see an **AnnPrecip** attribute which is the mean annual precipitation at each gage in mm.

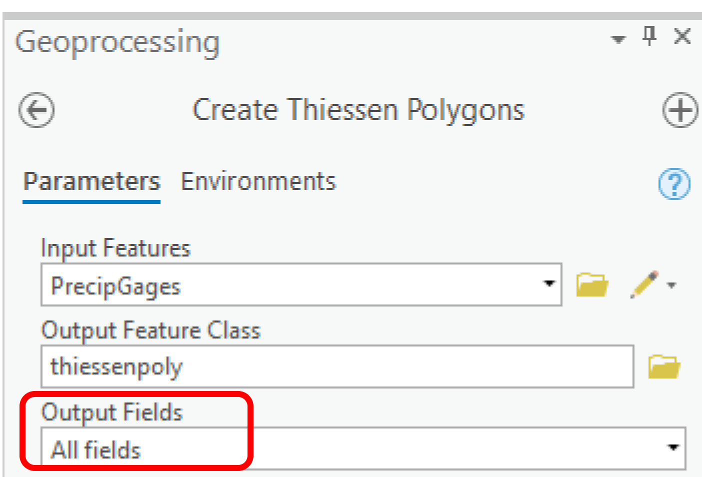



| OBJECTID | Shape | SiteName | SiteCode | FullSiteCo | Latitude | Longitude | Elevation | d1 | d2 | nd | nm | annprecip |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Point | BEAR LAKE SP | USC00420487 | GHCN:USC00420487 | 41.9583 | -111.3922 | 1806.9 | 1/1/1989 | 6/30/2017 | 10407 | 29 | 347.359211 |
| 2 | Point | BRIGHAM CITY WAS... | USC00420928 | GHCN:USC00420928 | 41.5239 | -112.0436 | 1289.3 | 1/1/1974 | 6/30/2017 | 15886 | 32 | 399.520186 |
| 3 | Point | CUTLER DAM | USC00421918 | GHCN:USC00421918 | 41.8328 | -112.0558 | 1307.6 | 1/1/1980 | 6/30/2017 | 13695 | 32 | 427.072792 |
| 4 | Point | HUNTSVILLE MONAS... | USC00424135 | GHCN:USC00424135 | 41.2403 | -111.7131 | 1566.7 | 1/1/1976 | 12/31/2013 | 13879 | 27 | 551.386765 |
| 5 | Point | LAKETOWN | USC00424856 | GHCN:USC00424856 | 41.825 | -111.3208 | 1822.7 | 1/1/1900 | 6/30/2017 | 42914 | 32 | 370.666283 |
| 6 | Point | LOGAN RADIO KVNU | USC00425182 | GHCN:USC00425182 | 41.735 | -111.8564 | 1364 | 1/1/1956 | 6/30/2017 | 22461 | 32 | 426.836988 |
| 7 | Point | LOGAN UTAH ST UNIV | USC00425186 | GHCN:USC00425186 | 41.7456 | -111.8033 | 1460 | 1/1/1893 | 6/30/2017 | 45470 | 31 | 493.154006 |

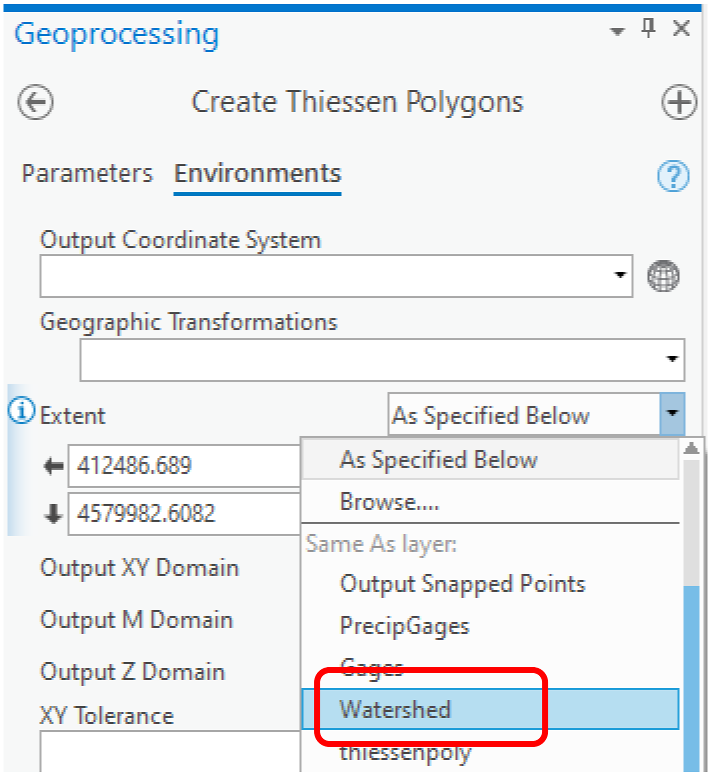
Select the tool **Analysis Tools → Proximity → Create Thiessen Polygons**




Specify **PrecipGages** as the Input Features.  Save the output feature class in the LittleBearLogan feature dataset and indicate that **ALL** fields should be output.  By saving to the LittleBearLogan feature dataset you ensure that the Thiessen polygon feature class inherits the spatial reference information from this feature dataset, keeping all your work in a consistent spatial reference.  Click OK.  It's really important that you select "All" here to carry the attributes of the Precipitation stations to the polygons associated with them.

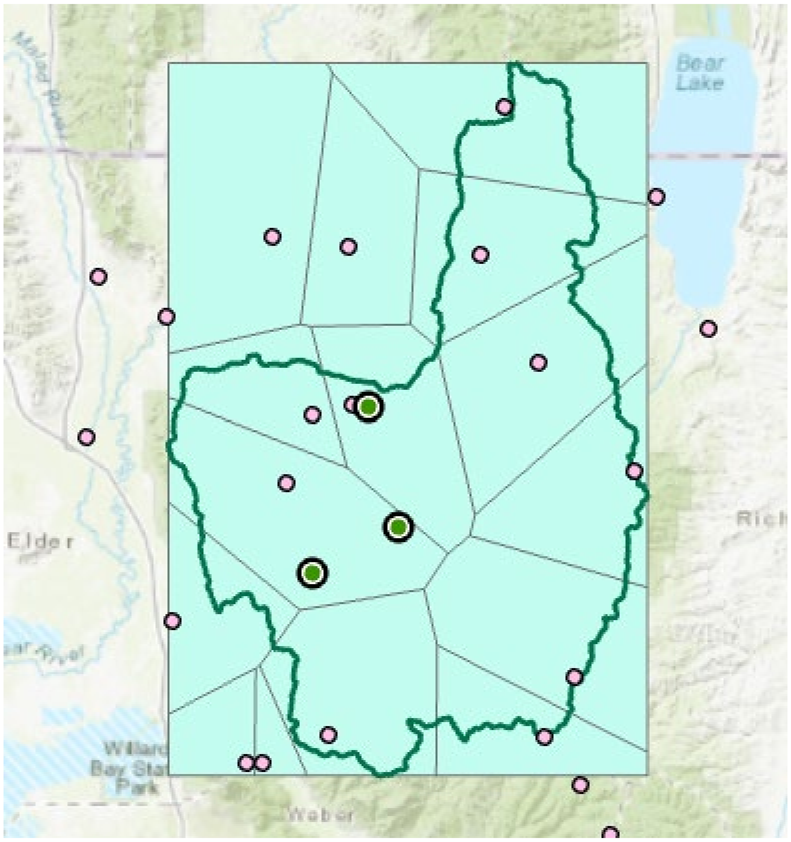


Switch to Environments and for Extent select Watershed




This is important to avoid the polygons not completely covering the watersheds being used.

The result is a Thiessen polygon feature class. This tessellates the landscape into regions that are closer to a particular gage than to any other.

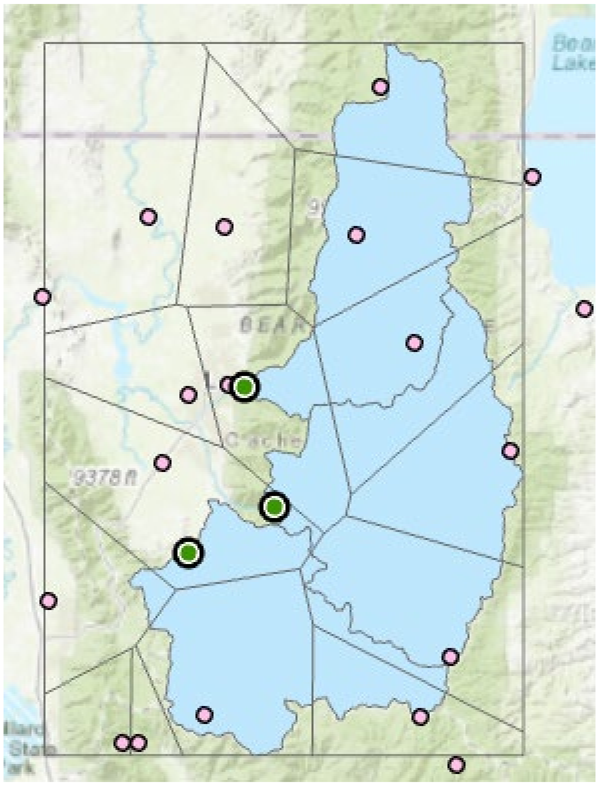



Here is what your attribute table should look like for thiessen polygons. If it doesn't have all these attributes at the right hand end, delete the result you just computed and do it over with the ALL option selected to make sure you transfer all the attributes from the gages to the polygons.

Field: Add Delete Calculate Selection: Zoom To Switch Clear Delete Copy

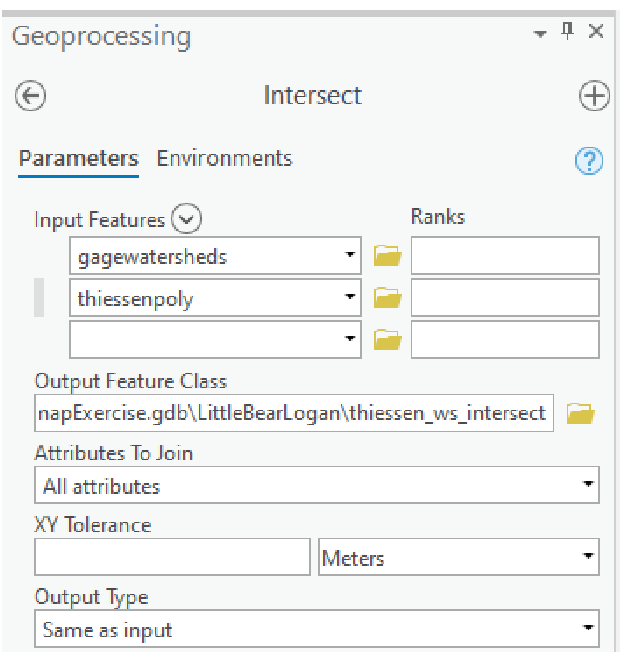
| OBJECTID | Shape | Shape_Length | Shape_Area | Input_FID | SiteName | SiteCode | FullSiteCo | Latitude | Longitude | Elevation | d1 | d2 | nd | nmo | annprecip |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Polygon | 40000.767462 | 93490066.044634 | 16 | Ben Lomond Peak | USS0011H08S | GHCN:USS0011H08S | 41.38 | -111.94 | 2438.4 | 1/1/1978 | 6/30/2017 | 14425 | 330 | 1458.708777 |
| 2 | Polygon | 80658.171802 | 378789146.855697 | 23 | Monte Cristo | USS0011H57S | GHCN:USS0011H57S | 41.47 | -111.5 | 2731 | 1/1/1978 | 6/30/2017 | 14425 | 327 | 993.26627 |
| 3 | Polygon | 71337.626833 | 342119071.543406 | 18 | Little Bear | USS0011H25S | GHCN:USS0011H25S | 41.41 | -111.83 | 1994.6 | 1/1/1978 | 6/30/2017 | 14425 | 327 | 875.193497 |
| 4 | Polygon | 32124.462381 | 39419189.51191 | 19 | Ben Lomond Trail | USS0011H30S | GHCN:USS0011H30S | 41.38 | -111.92 | 1776.7 | 1/1/1980 | 6/30/2017 | 13695 | 327 | 1059.625324 |
| 5 | Polygon | 62649.243508 | 198295801.291669 | 2 | BRIGHAM CITY WAS... | USC00420928 | GHCN:USC00420928 | 41.5239 | -112.0436 | 1289.3 | 1/1/1974 | 6/30/2017 | 15886 | 323 | 399.520186 |
| 6 | Polygon | 67870.409471 | 207292640.501138 | 22 | Dry Bread Pond | USS0011H55S | GHCN:USS0011H55S | 41.41 | -111.54 | 2545.1 | 1/1/1978 | 6/30/2017 | 14425 | 330 | 783.452703 |
| 7 | Polygon | 77926.567362 | 323109363.206263 | 20 | Tony Grove Lake | USS0011H36S | GHCN:USS0011H36S | 41.9 | -111.63 | 2582.9 | 1/1/1978 | 6/30/2017 | 14425 | 327 | 1222.911655 |

If you rearrange the map display you can get a map looking something like the below. What we're going to do is to find the area of each thiessen polygon that overlays each gagewatershed. This is done using the **Intersect** function, one of the most powerful functions of spatial analysis.

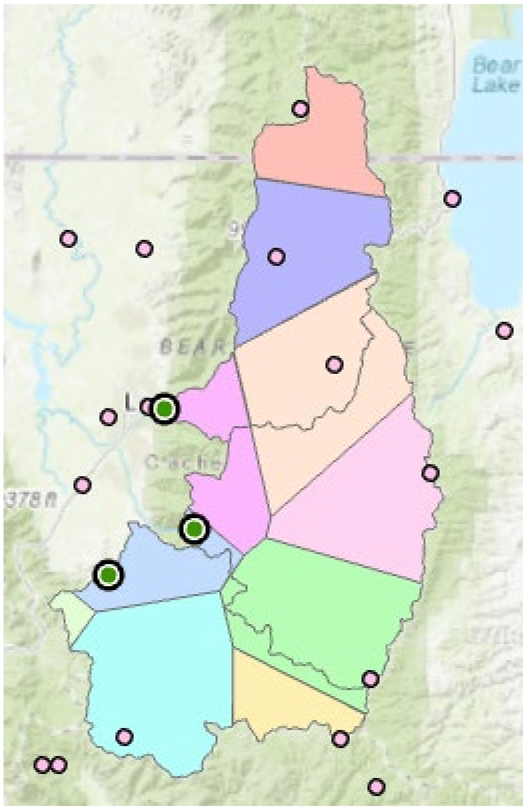



To average precipitation values in these polygons over the subwatersheds we need to intersect the thiessen polygons with the gage watersheds and compute area weighted averages for each subwatershed. The following calculations achieve this.

Use the search window to locate the **Intersect (Analysis)** tool and set the inputs as follows



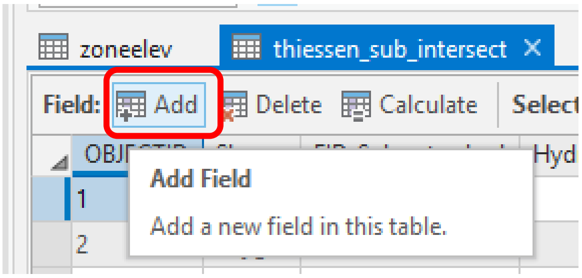
Following is the result, the thiessen_ws_intersect polygons symbolized with **SiteCode** as the Unique Value field – this is the identifying code of the rain gage in the Global Historical Climate Network (GHCN).



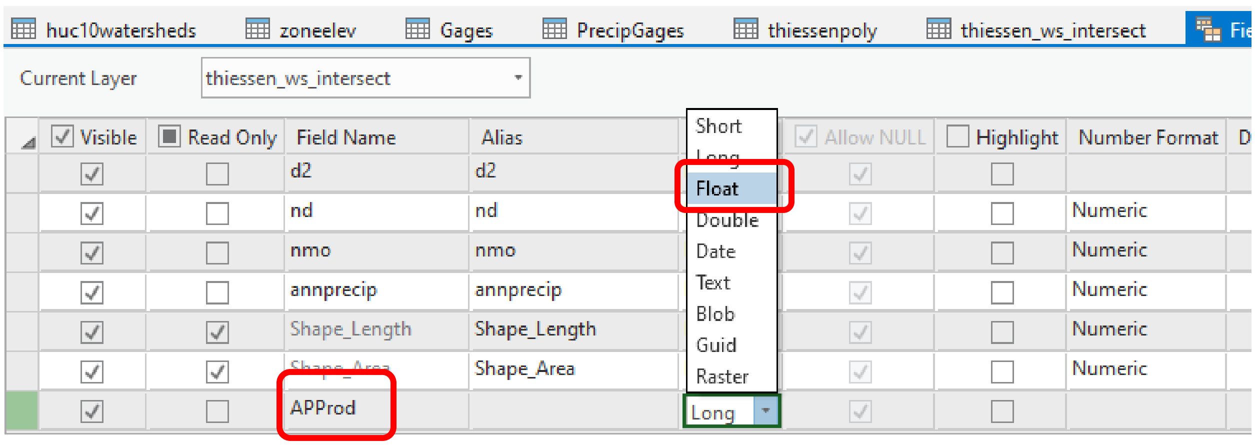

If you open the ThiessenSubIntersect attributed table you will see that from the 3 subwatersheds there are now 14 polygons, each contributing to part of a subwatershed and associated with a single rain gage. Let $\mathbf{P_k}$ denote the precipitation associated with each rain gage and $\mathbf{A_{ik}}$ the area of intersected polygon associated with rain gage k and subwatershed i. Then the area weighted precipitation associated with each subwatershed is

$$P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}}$$

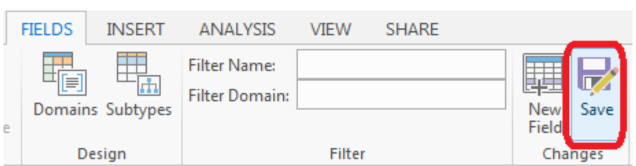
Open the attribute table for the intersected thiessen polygons and add a new field to the table, **APProd**.



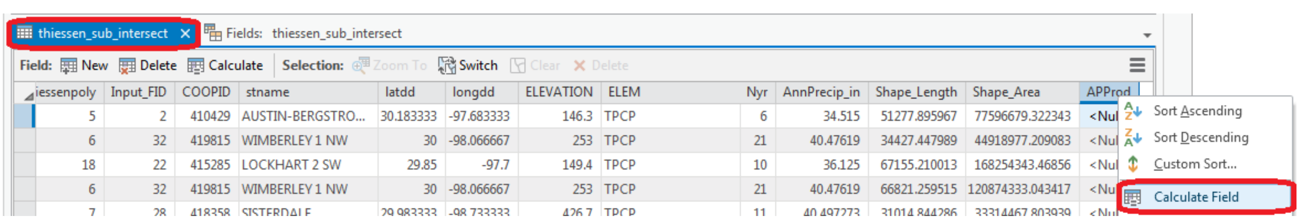

Double-click on the greyed-out “Data Type” column, where it says Long, and change the Data Type of APProd to **Float**. If you don’t change this data type, your calculations will fail on a datatype mismatch error.



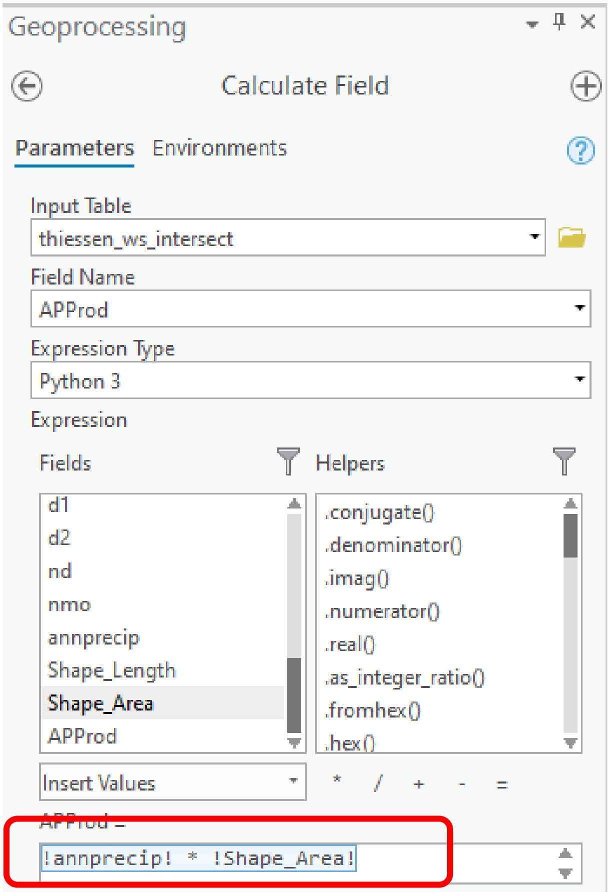

Make sure to save your changes using the save button in the **Fields** tab at the top of the screen.



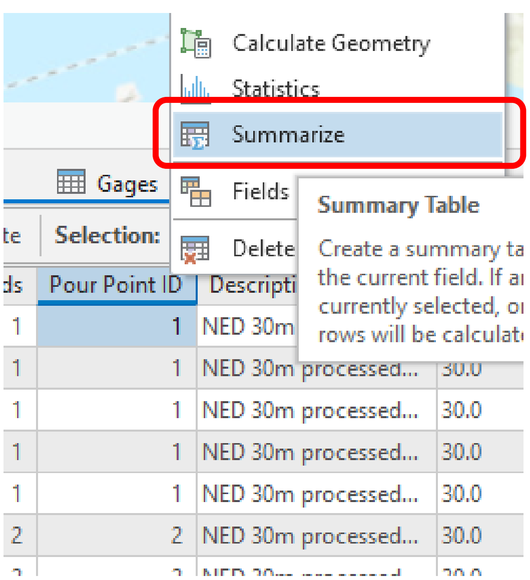

Go back to the thiessen_sub_intersect polygon attribute table and right-click on the header of APProd, selecting “Calculate Field”.



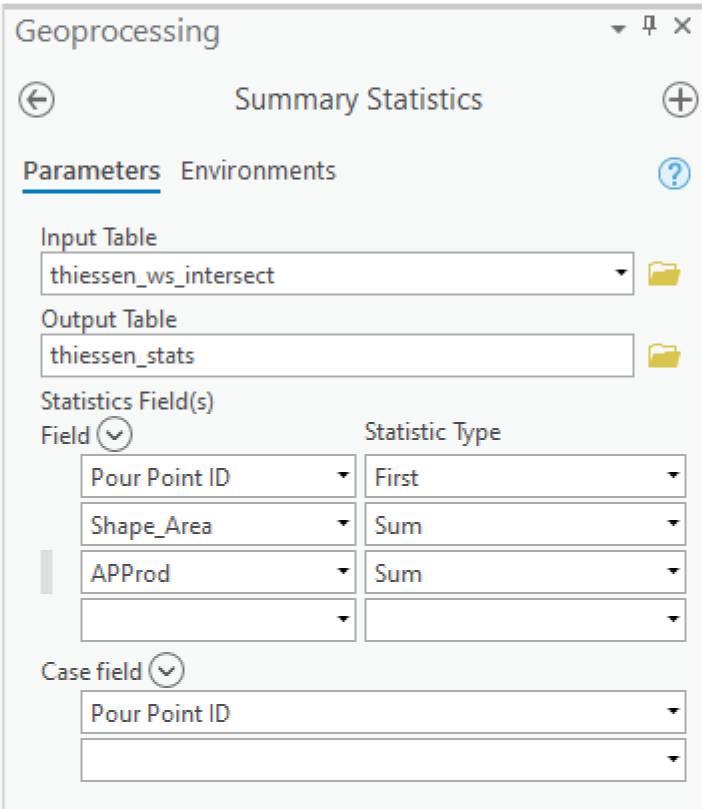
Create the expression **!annprecip! * !Shape_Area!** and click Run.



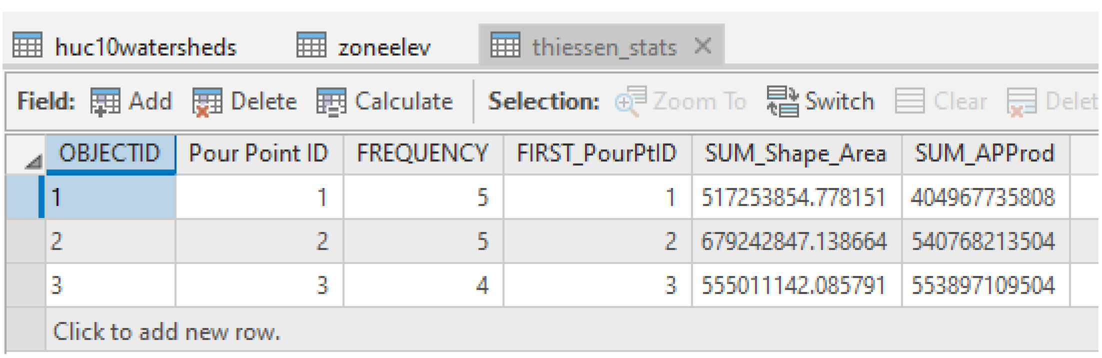

The result is a new field with the numerator terms for the equation above. Now locate the column Pour Point ID. These are unique identifiers for each gage watersheds (1, 2, 3 assigned during their creation). Right click on the header and select Summarize



Carefully select the summary statistics you need.  I selected the following: Pout Point ID - First, Shape_Area - Sum, APProd – Sum, and the Pout Point ID Case field.  Click Run.

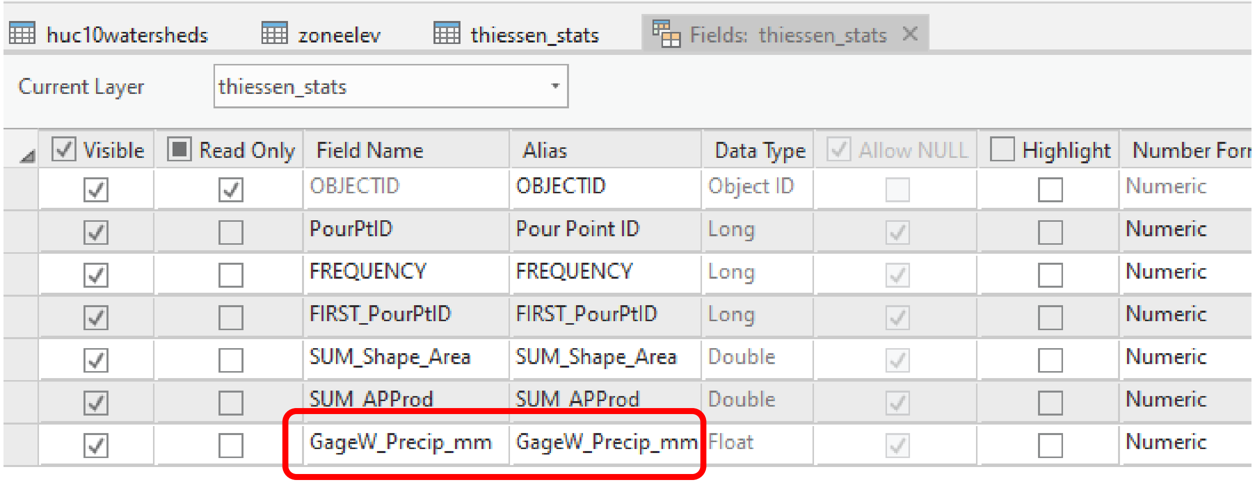



Navigate to your output table, and you'll see that the resulting table gives the numerator and denominator in the equation above for each subwatershed.

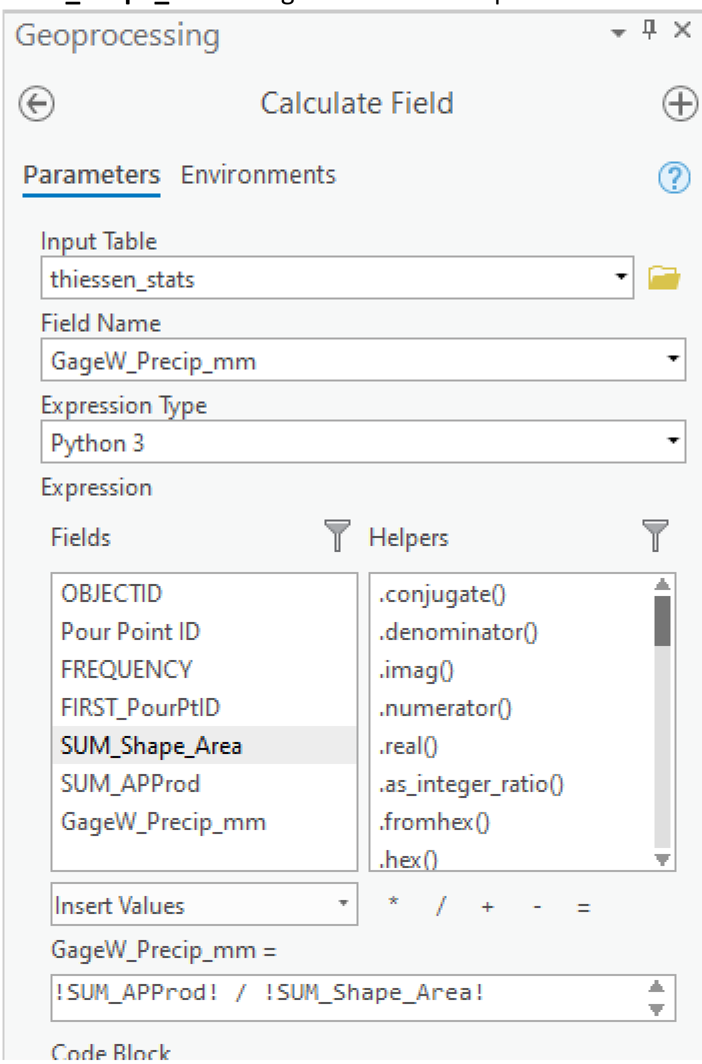



| OBJECTID | Pour Point ID | FREQUENCY | FIRST_PourPtID | SUM_Shape_Area | SUM_APProd |
|---|---|---|---|---|---|
| 1 | 1 | 5 | 1 | 517253854.778151 | 404967735808 |
| 2 | 2 | 5 | 2 | 679242847.138664 | 540768213504 |
| 3 | 3 | 4 | 3 | 555011142.085791 | 553897109504 |
| Click to add new row. | | | | | |

Add a **New** field **GageW_Precip_mm** to this table, again as a Float, and **Save** the result.




Go back to the thiessen_stats table and use **Calculate Field** to evaluate this as **!Sum_APProd! / !Sum_Shape_Area!.** **R**ight click on the top of the field to open Calculate Field.

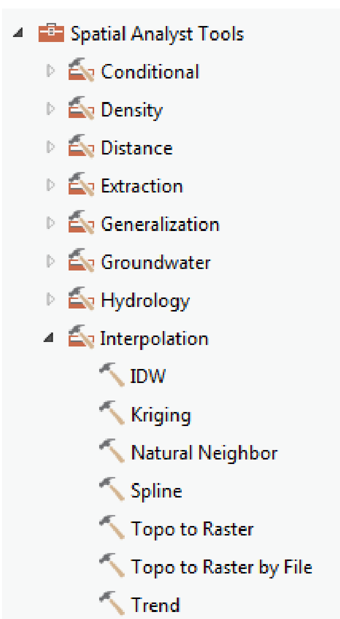


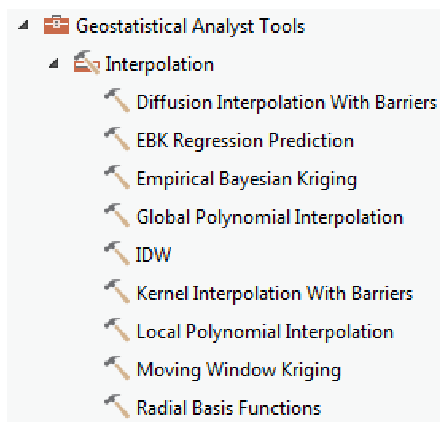
The result is the precipitation in mm for each subwatershed. This is pretty cool! And you can see how the tools in ArcGIS can give you a spatially area-weighted result that would be more tedious to derive otherwise.

*To turn in: A table giving the Pour Point Identifier, Name, and mean precipitation by the Thiessen method for each gage watershed. Determine the watershed names from their associated stream gages Which subwatershed has the highest mean precipitation?*

## 7. Estimate basin average mean annual precipitation using Spatial Interpolation/Surface fitting

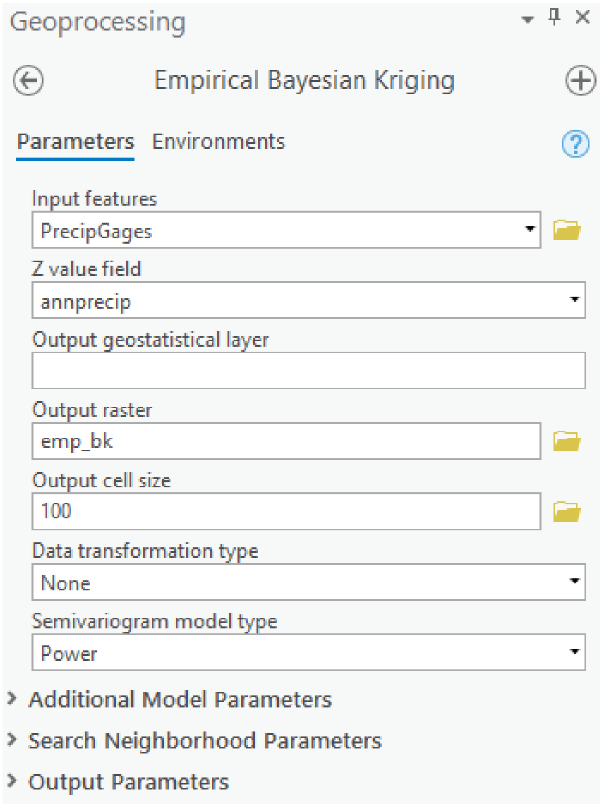
Thiessen polygons were effectively a way of defining a field based on discrete data, by associating with each point the precipitation at the nearest gage. This is probably the simplest and least sophisticated form of spatial interpolation. It also does not account for elevation adjustments. ArcGIS provides other spatial interpolation capabilities in both the Spatial Analyst and Geostatistical Analyst Toolboxes. Following are the interpolation tools in each.



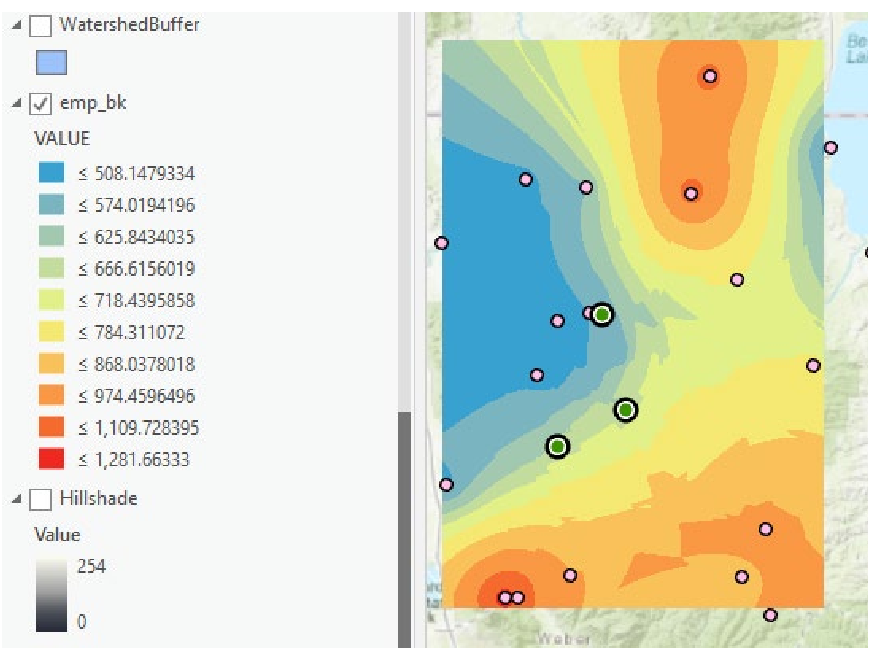

We will not, in this exercise, concern ourselves too much with the theory behind each of these methods. You should however be aware that there is a lot of statistical theory on the subject of interpolation, which is an active area of research. This theory should be considered before practical use of these methods.

In preparing this exercise I experimented with Empirical Bayesian Kriging which is reported to be one of the most advanced of these. I found that it took a very long time to complete, however you are welcome to try it with the following inputs. Use the input points from "PrecipStn" and Z value field as "AnnPrecip_in". Set the output cell size to 100 m to improve the spatial resolution.

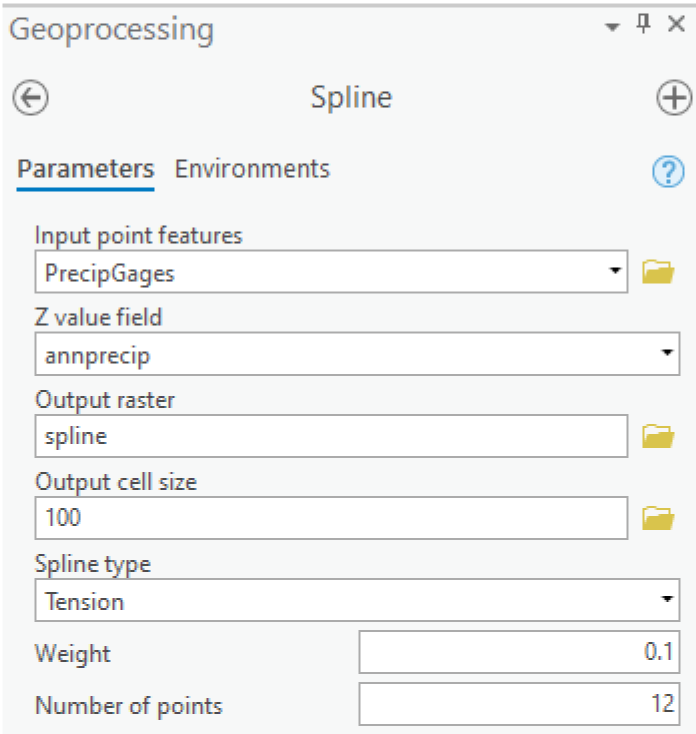



Also set extent to watershed to make sure the result covers the area you want.

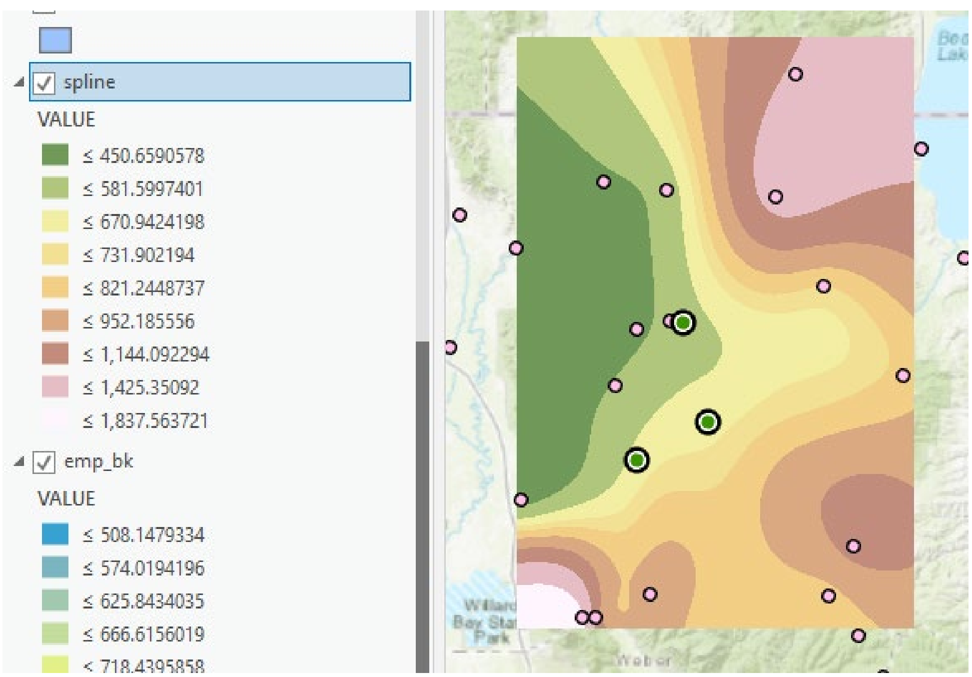
Following is the result from Empirical Bayesian Kriging



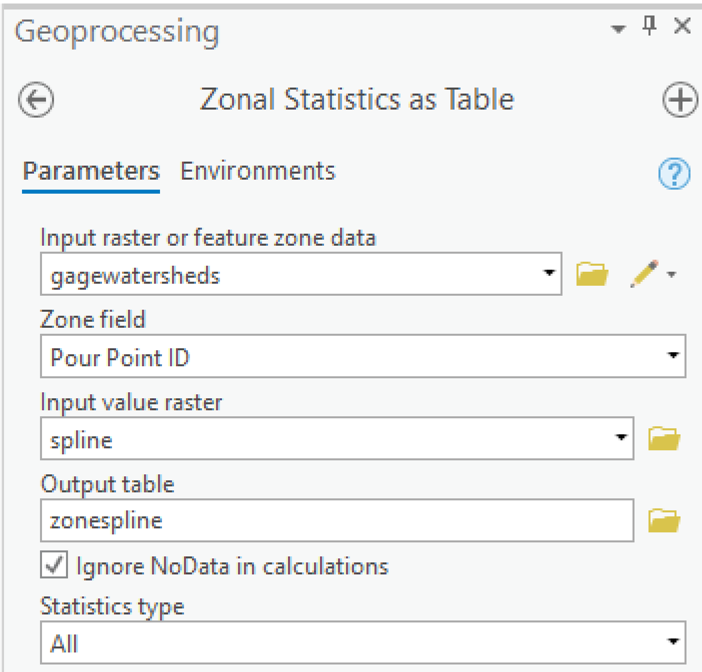
Following are inputs for tension **Spline** interpolation (Spatial Analyst tools). Use the input points from **PrecipGages** and Z value field as **annprecip**, and set the spline type as **Tension** with parameters as follows. I reduced the output cell size to 100 m to improve the spatial resolution. The result follows:




This runs a lot faster and the result is smoother than Empirical Bayes Kriging.



Now, let's use Zonal Statistics to compute the average value of the spline precipitation map over each subwatershed. Select **Spatial Analyst Tools → Zonal → Zonal Statistics as Table**. Set the inputs as follows:




Click Run. A table with zonal statistics is created. This contains statistics of the value raster, in this case mean annual precipitation from **Spline** over the zones defined by the polygon feature class **ggewatersheds**.

huc10watersheds | zoneelev | thiessen_stats | zonespline

Field: Add Delete Calculate Selection: Zoom To Switch Clear Delete Copy

| OBJECTID | PourPtID | COUNT | AREA | MIN | MAX | RANGE | MEAN | STD | SUM |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 51723 | 517230000 | 506.085571 | 980.356689 | 474.271118 | 768.436626 | 76.505703 | 39745847.627899 |
| 2 | 2 | 67928 | 679280000 | 581.322266 | 1014.800232 | 433.477966 | 781.416452 | 114.541129 | 53080056.766174 |
| 3 | 3 | 55523 | 555230000 | 526.560364 | 1275.653076 | 749.092712 | 1010.87846 | 238.608714 | 56127004.71051 |

Click to add new row.

The PourPtID in this table may be used to join it to the attribute table for the gagewatershed feature class. As for the elevations above this joined statistics table can be exported to Excel for formatting to prepare your turn in results.

*To turn in: A table giving the Pour Pt ID, Name, and mean precipitation by the Tension Spline method for each gage watershed. Which subwatershed has the highest mean precipitation using a Tension Spline interpolation?*

We will stop here. There are other things that would be interesting to do. I am going to list them for you to explore, but not make as part of the exercise as this is long already.

1. Use zonal statistics to determine the elevation of each rain gage. Cross check this against elevation from GHCN.
2. Develop a relationship between elevation and annual precipitation. We know that precipitation in this area is orographic, so a relationship is expected.
3. Use the elevation – precipitation relationship to calculate a grid of precipitation estimated from elevation and average this over watersheds. Compare this to the area average watershed computed from spline interpolation or thiessen polygons that operate in the horizontal plane.
4. Examine annual steamflow at the stream gages that define watershed outlets. Convert this to depth (volume / area) and compare to precipitation depth. Streamflow depth/Precipitation depth is runoff ratio, and tells us the fraction of precipitation that manifests as streamflow.

## Summary of Items to be Turned in:

1. *The number of columns and rows in the projected DEM. The cell size of the projected DEM. The minimum and maximum elevations in the projected DEM.*

2. *A screen shot showing the location of the highest elevation value in the Little Bear Logan DEM.*

3. *A layout with a depiction of topography either with elevation, contour or hillshade in nice colors. Include the streams from NHDPlus and watershed and sub-watersheds from the BasemapExercise.gdb LittleBearLogan feature dataset.*

4. *A table giving the HUC10, mean elevation, and elevation range for each watershed in the huc10 watersheds feature class. Which watershed has the highest mean elevation? Which watershed has the largest elevation range?*

5. *A table giving the Pour Point Identifier, Name, and mean precipitation by the Thiessen method for each gage watershed. Determine the watershed names from their associated stream gages Which subwatershed has the highest mean precipitation?*

6. *A table giving the Pour Pt ID, Name, and mean precipitation by the Tension Spline method for each gage watershed. Which subwatershed has the highest mean precipitation using a Tension Spline interpolation?*

### Appendix.

This appendix describes the use of CUAHSI data services (http://data.cuahsi.org/) and the CUAHSI WaterML R package (https://www.cuahsi.org/data-models/discovery-and-analysis/) to assemble the data for this exercise. However there were some difficulties with the WaterML package for the GHCN service so I used the RNOAA package to actually get the data. The work done in preparing **LittleBearLoganAnnPrecip.csv** is detailed in **AssembleGHCNData.R**.

The steps followed were

1. Install necessary R packages.
2. Get list of CUAHSI data services using **GetServices**().

3. Identify which service is for the Global Historical Climatology Network. This has server http://hydroportal.cuahsi.org/ghcn/cuahsi_1_1.asmx?WSDL
4. Get list of sites from this server **GetSites(server)**
5. Output sites to a CSV file, import to ArcGIS to see where they are located.
6. Use a spatial query to select sites inside and within 20 km of Little Bear River subbasin boundary.
7. Read these local sites into R
8. Use **GetSiteInfo()** for each of these sites to identify the period of record of precipitation data.
9. Select only sites with more than 10 years of data
10. Use a NOAA data service **ncdc()** from RNOAA R package to download the data.
11. Use R to compute annual average precipitation for sites with sufficient data and write the results.